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INTRODUCTION AND METHODS

Avicenna (980 - 1037 A.D.) was a Persian physician and philosopher whose *Canon of Medicine* became one of the most influential texts in the history of medicine. [14] His book was translated into Latin and brought to Europe where it flourished for hundreds of years. The *Canon* was widely taught in Western medical schools until the end of the eighteenth century and was a founding block of medical education. The writings of the early Greek scholar Galen (130 - 200 A.D.) are generally regarded as a major source for the *Canon*. [16], [20] Avicenna adapted much information, especially data regarding human anatomy, from Galen. [22], [28] However, Avicenna also arranged Galenic doctrines in a novel and systematic fashion, adding a logical organization to the ancient anatomist's often rambling texts and innumerable manuscripts. [1], [9], [18]

Avicenna codified Galenic teachings so it could be easily translated into Latin and brought to the West, where it became a vital part of medical curricula. [7] It is unclear if Avicenna himself ever actually performed dissections, yet the discourses on anatomy found in the *Canon* have a remarkably broad base. [20] Many parallels exist between the statements of the two authors, yet Avicenna is credited with some strikingly original observations. [8] It has been noted that he provided the first description of trigeminal neuralgia. [3] Avicenna also recognized distinct types of central and peripheral facial paralysis and accurately described meningitis and pituitary apoplexy. [27],[37]

Avicenna owes much to Galen, whose works are by far his most important source. However, there are important distinctions between the two writers. Galen did not differentiate between the theory of medicine

and its practical applications. [29] Avicenna draws a sharp line and separates theory and practice into two distinct areas of study. Avicenna's writing is scientific, brief and analytical, as if summarizing all of medical knowledge so it could be easily memorized by his pupils. Galen leisurely wove his ideas on physiology with detailed anatomy, added personal observation and anecdote, and criticized those who held opposed views. [25] Avicenna, as an Islamic writer whose purpose in writing was at least in part to present Pagan knowledge to a fiercely monotheistic world, at times transformed Galenic concepts. [39]

Avicenna was an influential scholar within his own lifetime. There are accounts that Avicenna was an opinionated man given to excessive passions. He was known to indulge in frequent sexual relations and had a love of wine. In professional circles, he was often at odds with other scholars and provoked violent convictions. Avicenna dismissed mediocrity and scorned those he felt were intellectually inferior. [2]

Avicenna lived during the time of the Persian Renaissance, which had its roots in both Islamic culture and the ancient Persian civilization of Iran. The hybrid nature of the Renaissance is demonstrated in its scientific writings, literature and philosophy. The dichotomy of ideas can be understood with reference to the history of the country, which became a mixture of cultures, ethnicities and religions. The era produced an array of famed writers and thinkers, but Avicenna rose to a stature which persisted much longer and was more influential than any of the others. [2]

Avicenna's apparent goal in writing the *Canon* was to present a highly compressed yet comprehensive account of the whole of medical theory. He presents a set of physiological principles which attracted students for several centuries. Unified organization, clarity and brevity are

the hallmarks of the *Canon*. Minor omissions can be found, such as the lack of some illustrative examples, indications of divergent views of other physicians, or acknowledgment of inconsistencies within the body of Galen's work. However, Avicenna's great contribution was to take the Galenic corpus and make it more accessible. Galen's writings on medicine incorporate both theory and practice, add physiological concepts, interweave anatomical detail, records of personal experience and observations, and polemic against the holders of different scientific views. Avicenna assembled the vast and prolix works of Galen in a single masterpiece which became a founding block for Western medical education for many years.

This paper is an analysis of the neuroanatomy within Avicenna's *Canon of Medicine*. Narrow topics within Avicenna's books have been previously analyzed but there have been few attempts to interpret Avicenna's knowledge of neuroanatomy. [4], [6], [17], [19], [23], [29], [35], [36] There have been no studies of the specific areas where Avicenna's and Galen's neuroanatomical discourses overlap. Avicenna's concepts of neurophysiology have not been scrutinized. This paper examines the anatomy of the brain, cranial nerves, skull and vertebral column described within the *Canon of Medicine*. The primary reference is the most recent English edition of the work, a direct translation of the historic text from the original Arabic manuscript published in 1966 by Mazhar H. Shah and a critical correlation of relevant sections of this translation with the latest printing in Arabic. [5], [27], [37] Further correlations are made with the French translation of Avicenna's anatomy, carefully transcribed and richly commented by Pieter DeKoning. [11]

Avicenna's knowledge of neuroanatomy is compared to Galen's as presented in several classic texts, including "On Anatomical Procedures" and "On the Uses of Body Parts." [13], [15], [21], [29], [29], [30], [32] An assessment is made of areas of knowledge where the two writers overlapped and the original concepts advanced by Avicenna.

In addition to examining the neuroanatomical writings of perhaps two of Western civilization's most influential physicians, a synopsis of their lives is presented. The sources for this study are several secondary texts which detail the life and times of each author. [10], [25], [39] Their social, political and cultural milieu is briefly described insofar as it impacted upon the lives and careers of the two scholars. The greater body of Avicenna's and Galen's works is noted, as is their place within the fields of medicine and philosophy. [31], [38] Specific areas of the authors' neuroanatomy are summarized in this paper. Avicenna's and Galen's statements regarding the structure and function of the brain, cranial nerves, spinal cord, skull and vertebrae are presented in epigrammatic format. These areas are compared and contrasted in order to examine the similarities between Avicenna and Galen. Attention is paid to the precise differences between the two writers' interpretations of neuroanatomy.

Although well known as the great organizer of Galen, Avicenna also made original contributions to knowledge of neuroanatomy. By focusing on the discourse of the central nervous system and its associated structures, this paper attempts to present an understanding of the Galenic tradition in the writings of Avicenna. Similarities between the two authors illustrate how Avicenna, writing some eight hundred years after Galen, incorporated classical Greek anatomical studies in his doctrine of medicine. In describing and analyzing the areas where Avicenna departed from Galenic

knowledge the advances he made to medicine can be better understood. Avicenna relied upon a strong Greek tradition, but was also able to provide original observations and brought his own medical, physiologic and philosophic theories to the *Canon*. This paper examines the similarities and differences of the two influential authors in order to disclose the Galenic heritage in Avicenna's text as well as illustrate some of the originality of the *Canon of Medicine,* specifically in the area of neuroanatomy.

LIFE AND TIMES OF AVICENNA

Historical Background

The period immediately prior to the life of Avicenna was a remarkable time of cultural, political and philosophic development in the Middle East. With ascendance of the 'Abbasid Caliphate of Baghdad in the year 750 A.D., various ethnicities blended and promoted learning. Arabs, Christian Syriacs, and Harranians contributed to this era. However, Persians fared especially well as the leaders in administration and state finance. Their language came to dominate political affairs, whereas the classics of literature and poetry were largely written in Arabic. Linguistic form and regional differences in dialect and language impacted upon the writing style that was later used for a multitude of important works, including the texts of Avicenna and his contemporaries. Various groups of importance emerged, including the Mu'tazelites, an influential school of theologians. Their style of writing became the model for the Persian Umayyad period in Syria and Iraq. [4] During this time Arabic prose and poetry was reaching its height and Islamic philosophy began to take shape.

Sciences in the middle east, particularly the study of medicine, philosophy, physics and mathematics was strongly influenced by and dependent upon the availability of classic texts, typically written in Greek and translated to Persian or Arabic. Persia received Greek learning by way of various routes during this early period of intellectual growth. Learning was possibly at its highest point under the Caliphate of al-Ma'mun (d. 833). The Caliph was deeply moved by the teachings of Ibn al-Muqaffa' who was said to have introduced Aristotelian logic to the Islamic world. Caliph al-Ma'mun supposedly once heard Aristotle speak to him in

a dream and was inspired to send scholars to Asia Minor and Cyprus to acquire a large collection of Greek texts. He proceeded to lavish gifts upon scholars, poets and translators at his medico-philosophical school of Gundishapur in southern Persia. Other routes of scholarly transfer were via academies of philosophy, which had been founded at Alexandria and eventually were brought to Antioch after Arabs conquered Egypt. The Bishop of Antioch had founded a religious school in his city which employed classical Greek methods of debate and philosophic discourse as early as 325 A.D. following the Council of Nicea. Additionally, Christian communities were instrumental in transplanting Greek culture to Syria and northern Iraq. [2]

Famous scholar-physicians began appearing in the intellectual and cultural arena. Just before Avicenna's birth another legendary physician of the Islamic world published his major texts. Abu Bakr Muhammad ibn Zakaria al-Razi, known to Europeans as Razes (d. 925 A.D.), was considered the preeminent clinical genius of his time. He was born in Raiy (Rhages) and, after being a poet and singer, studied medicine in Baghdad where he became the head of a hospital. In addition to medicine, Razes compiled a number of works on philosophy, in which he took the unusual view of denouncing Aristotle and proclaiming the superiority of Plato and Socrates. He also stated there was no need for prophets and urged individuals to achieve salvation on the basis of their own intelligence, choices and faith. However, it was with his medical text that Razes achieved lasting fame. [24]

The center of Islamic culture had been transferred from Damascus to Baghdad during the period of the 'Abbasid Caliphate in the middle of the first millennium. By Avicenna's time the Caliphate's central control was

weakening and strong local dynasties were on the rise. Persians took advantage of the crumbling power of Baghdad and, on a tide of national feelings, politically detached themselves from the 'Abbasids and made Bukhara, in Transoxiana, their capital, which was the seat of the Persian Renaissance under the court of the Samanids about 900 A.D. Bukhara was also near the city where Avicenna was born and spent some years. The Samanid dynasty reigned for about a century with an exceptional degree of cultural and political liberality. Some of its most celebrated figures, including Avicenna, came from the frontier regions such as Transoxiana between Persia and Chinese Turkistan. Although Persia had been under Arabic rule directed from Baghdad to the south, the natives fought, vehemently at times, to preserve their own identity through their common language, poetry and literature. Poets began to refuse to write in any tongue except their native Persian. The combination of cultures led to the characteristic hybrid literature and philosophy of the time. The intermingling of Arabic and Persian history and politics led to a dichotomy of ideas which was evident in science and philosophy and reflected the socio-political landscape. Islamic philosophy is by nature synthetic, as compared to the Greek which bears the hallmark of the analytic method. Islamic writers were theocentric in contrast to the more anthropocentric flavor of Aristotelian thinkers.

Late in the tenth century three local dynasties, on the geographic fringe of the Samanid territory, dominated political life and heavily influenced Avicenna's career and movements. The Ziyarids seized power in 928 A.D. and held the region around the Caspian. To the west were the Buyids, a Persian noble family, who won control over entire Persia and eventually took Baghdad itself by 945 A.D. The Ghaznavid dynasty which

came from the eastern border of the region, succeeded in pushing back the Buyids, absorbing the Ziyarids and overthrowing the Samanids, was led by Sultan Mahmud, who eventually conquered all of Persia. Although he was the son of a Turkish slave, the ruler showed a great appreciation for Persian arts and spent a small fortune each year promoting writers and artists. Sultan Mahmud had been so impressed by the fame of Avicenna that, at one point, he became involved in a dispute to retain the scholar for his own *salon* (see below). [2]

During the 'Abbasid Age the conquering power of religion met the restraining discipline of rational analysis and explanation, brought to the region by those scholars who reveled in the concepts and meditations of classical Greek authors. Many minds labored at reconciliation and synthesis of the diverse camps of philosophy and theology. The 'Abbasid was the period when Islamic civilization was changing and developing, and Avicenna's work can be considered the culmination of this influential time in history. [2]

Avicenna was said to belong to a triumvirate of thinkers who dominated the Persian Renaissance, the other two being Kindi (born Kufa in the middle of the ninth century) and Abu Nasr al-Farabi (d. 950 A.D.). There were numerous physician-philosophers during this time, Avicenna among them, and included Razes, Miskawaih, Beruni, and Ibn al-Khammar, who was called "the second Hippocrates." [2] For them medicine was a profession and philosophy was an intellectual pastime which became a useful shield against political hostilities. They were scattered all over the Islamic world and a number were in Persia and Transoxiana. Usually trained in Baghdad as Razes was, they were held in high esteem by political rulers and were often able to overcome religious and ethnic

barriers. Tolerance of different theologies and cultures was a phenomenon which vacillated depending on the whim of the king and his particular court. Interestingly, the scholar-physicians could often take advantage of the popularity of their academic fame and maneuver between ethic and cultural battlegrounds.

Avicenna's Life

All accounts the life of Avicenna are based on his autobiography which the physician wrote for a number of years and was completed by a loyal pupil, Juzjani. [33] Abu Ali al-Husayn ibn 'Abdallah ibn al-Hasan ibn 'Ali Ibn Sina, which by way of Hebrew became Europeanized into Avicenna, was born in August, 980 A.D., near the Samanid capital of Bukhara in a large village called Kharmaithan (The Land of the Sun), where his father had been appointed a local governor. Soon after Avicenna's birth the family moved to the larger city of Bukhara, where his early education and formative years began. [2]

In a famous quip from his autobiography, Avicenna says that by the age of ten he had memorized the Koran. [33] There is no way to verify his boast, however he did grow up in an intellectual atmosphere often engaging in discussions about theology and philosophy. As was common for well-to-do Persians, Avicenna's father hired a tutor for his son. The teacher quickly recognized his pupil's talents and advised the father that the boy should engage only in scholarly work. At an early age Avicenna read logic and Greek authors including Plato and Aristotle, whose writing had been translated into Arabic. Afterwards, he decided to take up medicine and proceeded to read all the available books on the subject, including the texts

of Galen and Razes. Avicenna once again casually boasts about his abilities in his autobiography and claims that he did not find medicine a "difficult science," and shortly excelled in the field. [4] After mastering medicine, he studied religious jurisprudence. By then, Avicenna was supposedly a mere sixteen years old.

During the next eighteen months, Avicenna concentrated on the various problems of philosophy. He claims to have worked every day without sleeping an entire night through and mastered logic, the natural sciences and mathematics. In another famous passage, Avicenna says that whenever he encountered difficulty he would retire to prayer and meditation in a mosque. At other times, when he felt overcome by sleep, he would consume a glass of wine and return to work. [26]

At this point, the reigning prince at Bukhara, Nuh ibn Mansur, fell ill. Avicenna's fame had spread by then, and the scholar-physician was summoned to tend to the prince. Avicenna is credited with helping to cure the prince and as a result, became enrolled in his service. This way, he gained special permission to visit the royal library, which consisted of a mansion of many rooms, each devoted to a particular subject and containing chests full of books. Avicenna eagerly devoured the section dedicated to Greek writings. Unfortunately, this library was soon after destroyed by fire. [27]

Avicenna was about twenty-one years old at this stage and began writing his *oeuvre*. His first texts were on law and ethics. [2] About this time Avicenna's professional situation changed with the abrupt death of his father. For unclear reasons, he became obliged to move from Bukhara to Gurganj. Avicenna was probably the victim of racial or religious prejudices which had been present between the Samanids, his former

employers, and politically nascent Turks, who subsequently hired Avicenna in Gurganj. From the tone of his autobiographical writings and the fact that he began a period of frequent travel, it seems that he left in unhappy circumstances and began a more troubled period in his life.

Avicenna joined several famous scholars with whom he would later be associated with as leaders of the Persian renaissance, including Beruni, Khammar, Masihi and a painter named 'Arraq, who were all employed by the ruling Ma'munid prince in Gurganj for a number of years. Eventually, Sultan Mahmud, the powerful ruler well known for his love of Persian literature and philosophy, learned of the prince's esteemed group and sent an entourage to bring them to his own court. The others reluctantly agreed but Avicenna, along with the painter, 'Arraq, escaped Gurganj before the Sultan's envoy appeared. It is possible that Avicenna fled because Mahmud had the reputation of harshly treating those who were not religiously orthodox like himself. [2] Avicenna and his colleague experienced a difficult desert flight, which the painter did not survive. Avicenna had been traveling to find a new patron, the Amir Qabus, who lived in the northern territories. Unfortunately, the Amir had been imprisoned in a fortress and died before Avicenna arrived at his destination. He was forced to continue the exodus and avoid encounters with representatives of the Sultan, who had ordered that Avicenna be brought to his court under guard.

Avicenna finally arrived in the city of Gurgan, where he befriended his pupil and life-long companion, Juzjani, who took up the task of completing the account of his teacher's life. Juzjani would visit Avicenna every day, join in reading the *Almagest* and listen to his discourses on

logic. It was in Gurgan, that Avicenna also began writing the first part of the *Canon*. [2]

For obscure reasons, Avicenna decided to go from Gurgan to Raiy, birthplace of the 'genius clinician,' Razes. Raiy was a cultural and religious metropolis which had been home to several powerful political figures and contained a large library. Avicenna came into the service of the widow of the former prince, but was forced to leave when he sided with her son in the issue of who should be lawful ruler of the land. [2]

After some wanderings, Avicenna was employed in the city of Hamadhan by an influential court lady. The physician was called upon to cure the local Amir of colic, which he successfully treated. The ruler then made Avicenna his personal physician and took him on an expedition against the Kurds. Upon returning to Hamadhan, the Amir appointed Avicenna a vizier, which provided him with some political and social status. Following his debut as a political figure and administrator, Avicenna fell into difficulties with the local army. The soldiers arrested him and pillaged his belongings for unclear reasons. Avicenna escaped with his life only by favor of the Amir, who granted him amnesty. After a period of hiding, Avicenna was called for once again to treat the ruler for colic and, having been successful, was once again appointed vizier. At this point Avicenna completed the first book of the *Canon*. [2]

An account of Avicenna's daily life sheds some light upon the man's industry and diversity of talent. He was said to wake before dawn, write some pages of his *Kitab al-Shifa* (The Book of Healing), which is the longest of his extant works, and later call in pupils for a reading. After a large lunch at which he usually entertained a number of guests, Avicenna presented himself at court, where he would hold private sessions with the

Amir. [2] Thus, Avicenna managed to maintain a healthy academic career while holding political office and being something of a socialite. Such a high-profile and unconventional existence probably accounted for his far-flung reputation as well as explained the readiness of some of his governmental enemies to criticize him, particularly in light of the rigorous Islamic society in which they lived.

In the meanwhile, Avicenna's patron, the Amir died as a result of disease contracted while at battle with the Kurds. Avicenna once again was forced into seclusion in the house of druggist where his loyal pupil, Juzjani, urged the scholar to continue his writing. In this scenario, Avicenna completed the *Shifa* and the treaties on natural science and metaphysics. When his enemies discovered that Avicenna had been in correspondence with a rival ruler they cast him into a fortress prison for four months. While imprisoned Avicenna continued writing books on medicine and philosophy.

Eventually, a friendly prince and admirer of Avicenna, 'Ala' al-Dowleh, released and brought him to his own court. Avicenna had the opportunity to hold weekly meetings for learned men of all classes to discuss science and philosophy. Possibly, these were the happiest of times for Avicenna, who expressed deep gratitude to his patron, 'Ala' al-Dowleh, in the introduction of his Book of Logic. [2]

Juzjani digresses at this point in the biography to relate several episodes which suggest that Avicenna had an ego nearly as powerful as his legendary memory and intellect. The pupil states that he had never seen his master read a book all the way through. "Instead he used to look up the difficult passages and the complicated problems and see what the author had to say, so as to discover the state of his learning and the degree of his

understanding." [2] Juzjani relates another story of how Avicenna decided to master Arabic. One day in the court of the Amir, Avicenna expressed an opinion on Arabic linguistics. A scholar who was present criticized Avicenna and said he should remain a philosopher and not a linguist. Avicenna proceeded to learn Arabic, compose a number of poems of rare words and write three essays in various styles of Arabic. The essays were presented to the scholar who had taunted him, and Avicenna asked his opinion of the piece. The rival scholar was convinced that the writing was authentic Arabic and Avicenna was said to be immensely pleased. [2]

In 1030 A.D. Avicenna's patron, 'Ala' al-Dowleh, was forced to flee his city. Avicenna accompanied him on the flight and subsequent military campaigns. In the following years Avicenna contracted colic and, as he described it, "the epilepsy which sometimes follows colic." Avicenna attempted to treat himself by injections of celery-seed but was so weak he could hardly walk. He was known to have repeated the phrase, "the manager who used to manage me is incapable of managing me any longer, so there is no use trying to cure my illness." [2] Even though 'Ala' al-Dowleh succeeded in returning to Hamadhan and reestablish his reign, his physician remain depressed and ill. Avicenna died and was buried in Hamadhan during the late spring of 1037 A.D. at the age of fifty-eight. [34]

Avicenna lived in a time of religious revivalism and political upheaval which was strangely balanced by the emergence of Islamic philosophy and science. It is ironic that Avicenna stood at the pinnacle of the Persian renaissance while simultaneously, he invested a great effort into political flight. The Turkish rulers were known to have persecuted the Samanian leaders of Bukhara under whom Avicenna, his father and family had lived. His political misfortunes were probably related to the clash of

political and ethnic forces in which he was sometimes caught. Given the climate of hostility and fierce prejudices, it is a wonder that Avicenna managed to rise above the ethnic battles and ingratiate himself into the courts of various rulers, both Persian and Turkish. Avicenna took full advantage of his life's occasional peaceful periods to create an influential body of writing. Although his personal life was marked by frequent wondering in search of sponsors, the stability of his powerful intellect made possible his important works in philosophy and medicine, including the masterpiece, *The Canon of Medicine*.

WRITINGS OF AVICENNA

Over two hundred books have been attributed to Avicenna, however some of these are sections of works appearing under a different title and others are probably of dubious authorship and credit is merely given to Avicenna. About a hundred books can be reliably said to have been written by Avicenna and most have survived into the modern era.

Avicenna was influential in the area of linguistics as well as science. His contributions exist in medical and philosophic language, which he was able to categorize as well as rectify differences between Arabic and Greek. He classified vast quantities of information better than perhaps any other author. Avicenna organized and subdivided the elements of Greek anatomy, physiology, philosophy, astronomy, and metaphysics, and then proceeded to organize the details into coherent texts which were used by scholars in Persia, the Far East and Europe for generations. He helped establish Arabic philosophical terminology for a thousand years. [2]

Avicenna's *Canon of Medicine* had a profound effect upon medical education. For several hundred years, the book was used as the basis for medical school curricula. [37] It provided medical students with a coherent survey of the fundamentals of physiology set in the context of Aristotelian natural philosophy. Within that structure, Avicenna extended the Aristotelian teaching that an omnipotent creator set life in motion and was basically detached from the activities of the daily world. Avicenna put these ideas into the Islamic understanding of a monotheistic divine being.

The *Canon* had an unprecedented effect upon European medical thought. At least 60 editions were published between 1500 and 1674 and a substantial body of commentary was printed during that time. [31] At

Bologna part of the Canon retained a nominal position until 1800. The fact that a single text held such a significant position is a tribute to the organizational powers of its author. As one scholar said, "neither among the Greeks nor among the Arabs was there any single complete continuous book that taught the art of medicine [as well as the *Canon*]. Avicenna intended to reproduce all the monuments of medical art scattered at large in various works of Galen into one, as it were, corpus . . . .Indeed, he collected much dispersed information into appropriate and defined places and arranged it in sequence." Avicenna's book was favored because, comparatively, the Hippocratic writings were enigmatic and obscure, Galen was prolix and Razes, confusing. [31]

The twelfth century translation of the *Canon* by Gerard of Cremona (d. 1187 A.D.) was the original route of the book into European academia. [31] Its text was quickly accepted as the standard for medical knowledge and soon occupied a position of considerable significance in the Western universities. An example of one of Avicenna's innovations is the classification of bodily parts, which was adopted by the medieval faculties of medicine and used for hundreds of years.

Highlights of Avicenna's Canon

The first book of the *Canon* is titled *General Principles of Medicine.* Book I is divided into four main parts, or Fen, a term adapted from the Arabic by the Latin translator, Gerard of Cremona. The General Principles opens with definitions and proceeds to a survey of physiologic concepts. The second Fen classifies illness according to various parameters. Diseases are divided into those caused by an imbalance of the

four elementary qualities of hot, wet, cold, and dry, those caused by the unhealthy composition of organs, and those caused by trauma. Efficient causes of disease (see below), are categorized as problems in the environment, life-style, psychological make-up and various "non-naturals." Avicenna calls those things which exist outside of the body but have a direct effect upon it "non-naturals" and include air, food, drink, activities such excretion, motion, rest, sleep and physical events such as pain. Book I contains a section on symptoms which lists an array of individual signs of imbalance of elemental qualities and reviews the standard means of diagnosis by pulse and urine. The third Fen is about the conservation of health. Fen three includes separate sections of suggestions for pediatric, adult, geriatric patients, those who are delicate and complexionally imbalanced and travelers. The fourth Fen deals with principles of therapy and forms of treatment for different conditions. Therapy includes emetics, cathartics, sedatives, medications, bleeding, cauterization, blistering and enemas.

Book II is on the subject of simple medicines. Most of it is a list arranged in Latin alphabetical order of individual substances, their properties and conditions for which they are remedies.

Book III is composed of twenty-one Fen on ailments affecting each major organ of the body, arranged from head to toe, and their treatments. Most sections are preceded by chapters on the anatomy and physiology of the organ in question.

Book IV surveys diseases and injuries including a famous account on fevers. It also relates the concept of critical days in illness and provides a description of tumors, pustules, wounds, bruises, sprains and ulcers,

dislocations, fractures, and poisons of mineral, vegetable and animal origins including animal bites and stings and of skin conditions.

Book V is an antidotarium, or manual on the preparation of compound medications. [31]

Themes in the Canon

Book I of the *Canon* is much like a manual of Galenic anatomy and physiology, however the work contains elements of considerable importance and originality. Fen 1 deals with the theoretical part of medicine. In it, medicine is defined and its place discussed among the arts and sciences. Avicenna elucidates the principles of medical learning. In his discussion of the fundamentals of medicine, Avicenna separates the art into two distinct areas, theory and practice. [12]

Fen 1 opens with the famous definition: "Medicine is the science by which we learn the various states of the human body, when in health and when not in health, whereby health is conserved and whereby it is restored, after being lost." [27] Medicine is presented as a science in the Aristotelian sense that it is a body of knowledge derived from true premises and based upon rational thinking. The definition includes the notion that, as a science, it is a collection of ideals, and rejects the possibility that medicine is solely a practical art, technology or craft. As a scholar, Avicenna broadened the classical idea that only true sciences, such as philosophy and physics, are theoretical, thus strongly detached from the vulgar, physical world. He asserts that medicine is divided into both theory and practice, a definition which incorporates both classical concepts and the contemporary needs of the physician.

In the next chapter Avicenna states that the subject of medical science is the human body insofar as it experiences health and sickness. The causes of sickness are presented in Aristotelian manner and categorized into material, efficient, formal and final causes.

The "four causes" of Aristotle are an important philosophic notion. According to the legendary thinker, every person, event and thing can be described by its four causes, in other words, the forces which brought it into being and gave it purpose. Examining the four causes answers the questions Who, What, How and Why?, which are placed in increasing order of physical and ethical complexity. For instance, one could say that insulin has four causes. The "material cause" is the amino acids which compose its peptide sequence. Insulin's "efficient cause" is the islet cells of the Pancreas. The "formal cause" is the protein-producing mechanism of tRNA, rRNA, endoplasmic reticulum, etc. The "final cause" of insulin is a statement about its purpose, i.e., it functions to reduce plasma glucose, as well as a judgment of the greater need it serves. Thus, the final cause is also a statement of teleology: insulin helps the body process food. Avicenna use the Aristotelian scheme in relation to the causes of illness. He suggests that the physician must know symptoms, should investigate the four causes of diseases by observation and draw conclusions by incorporating his knowledge of anatomy.

Next, Avicenna presents the key elements in the foundation of Greco-Arabic medical theory. He discusses humoral physiology and *complexio*, or temperament and *krasis*, balance of the elementary qualities of hot, wet, cold and dry in living bodies. Humoral theory is based upon the idea that the body is composed of four elements, which mix in varying degrees in each organ. The two heavy elements, earth and water, combine

to form the physical substance of the body. The two light elements, air and fire, generate spirit and motion, which is also affected by the soul. Avicenna proceeds to elucidate the basic qualities of the elements, for example, that water receives all shapes but does not preserve them, air rarefies and elevates substances and fire assists in the process of maturation, mixing and making subtle.

In the last four subdivisions of Fen 1 Avicenna discusses the temperaments, the humors, parts of the body, the "virtues" and the "operations," which included sensation, motion, pulsation, etc. These categories, along with the elements and spirit, constitute the ancient scheme of the "things natural." Avicenna uses the Aristotelian four causes (material, efficient, formal, and final), to explain the seven "things natural." In his survey, Avicenna proceeds from the most remote (the elements) to somewhat remote (humors) to most immediate (the organs and spirit). He suggests that the virtues, or most complicated activities, are the final cause of the human body.

In his discussion of tissues and organs, called *similia* and *simplicia*, Avicenna makes divisions according to whether these parts receive or emit virtue. For instance, the flesh was supposed to receive virtue while the heart emitted it; the liver and brain both receive and emit virtues. These concepts are based upon Galen, who divides virtues into natural, vital and animal. Galen's theory corresponds to the threefold character of the soul as set forth by Aristotle. [31] Virtue was linked to the importance or primacy of that organ. Galenic doctrine states that there are three or four principle organs (the number differs in various texts) and secondary organs which serve the principles. The heart is a principle served by the

secondary lungs and arteries. Likewise, the liver is served by the stomach and veins.

Avicenna's definition of spirit follows the Galenic tradition of a highly refined substance formed by inspired air. Avicenna's innovation is that spirit is generated in the liver from a transformation of the humors, flows to the heart where it receives heat and then is transferred to the entire body via the arteries. He writes that it is fundamental in transmitting vital force, which keeps life in motion. The animal virtues seem to be related to modern neuropsychology and are responsible for sending messages from the senses to the brain. He concludes that the body requires the cooperation of both natural and animal virtues.

The *complexio*, or temperament of things, Avicenna defines as a physical quality which is unique to all individuals and things. Medications are described along a continuum of hot and cold. It was thought that the balance of particular elements within a medication affects the humors and spirit of a patient. Avicenna conceptually arranges individual body parts by way of temperament and places them in descending order of hotness, coldness, wetness or dryness. For example, the heart is considered innately hot and the skin, innately dry.

Avicenna states that the humors are liquids which are involved in nourishing the body. In addition to the four primary humors of blood, phlegm, red bile and black bile, Avicenna identifies four secondary humors, each of which have good and bad varieties. The beneficial humors are absorbed and provide nourishment; the remaining humors are damaging if not excreted.

The *Canon of Medicine* is a compilation of Galenic teachings and anatomy within the classical Greek intellectual architecture put forth by

Aristotle. Avicenna is both a philosopher and a physician and his dual academic stance is evident in the writing of the *Canon*. He opens with the reconciliation of medicine and philosophy, and asserts that medicine has the same intellectual gravity as that of the natural sciences. Avicenna's explanation of ancient humoral theory draws upon his knowledge of Galenic medicine, yet, he contributes his own formulations, as witnessed by his description of spirit and the temperaments. Avicenna organizes all of medicine into a relatively concise text of five volumes which includes descriptions of diseases, humoral theory, lists of medications and recommendations for treatments. It is not surprising that the book became an important fixture in European medical academia. As explored in the following sections, Avicenna's neuroanatomy also relies upon Galenic doctrine, but, as was his talent, he arranges it into a coherent format and adds some of his own opinions and theories on select issues.

SUMMARY OF AVICENNA'S NEUROANATOMY

AVICENNA ON THE BRAIN

Note: the following section is based on the most recent edition of *The Canon of Medicine* published in 1993, translation provided by Dr. Issam Awad. [5]

Avicenna's statements on the brain are found in Book III of the *Canon*. He begins the discourse with a statement describing the head itself. The subsection is called, *On The Usefulness of the Head and Its Parts*.

Avicenna discusses the role of the head, a definition which he refers to Galen. He says the head was not created to house the brain, nor any of the cranial senses because certain "lower animals" do not have a head, yet enjoy the same sensations. Avicenna makes the somewhat surprising statement that the function of the head to elevate the eye above the rest of the body. He states, "the eye is for the body what the scout is for the army, and the best place and the most convenient for scouts is the most elevated." Avicenna writes that some animals merely use an "elongation" to support the eye but others, need the additional "cranial nerves, to ensure various movements of the eye and eyelid."

Next Avicenna discusses the essential parts of the head and includes "the hair, the skin, the flesh, the cranial membrane, the thin membrane resembling the chorion, the brain, its substance and cavities and the content of these cavities, the two membranes situated beneath the brain, the admirable network (vessels under the brain), and lastly the bone forming the base of the brain."

In the next section, entitled, *On the Brain*, Avicenna discusses cerebral anatomy and includes the substance of the brain, the meninges and other structures.

Avicenna states that, "the brain consists of an enveloping substance, a medullary substance, and internal cavities filled with pneuma." The "cavities filled with pneuma" are the cerebral ventricles. Avicenna mentions that the cranial nerves are attached to the brain but are not part of it. He describes the longitudinal fissure which divides the brain into two parts which are contained within "envelopes," the meninges.

Avicenna states that the temperament of the brain, "is cold and humid." He explains that the brain is created cold because its many functions and activities, such as "movements of the nerves, the impressions of the senses and the transport of pneuma during alterations caused by imagination, thought and memory," which are hot, do not "inflame" the brain. He also states that pneuma, which come from the heart, the hottest of organs, "is very hot." The brain is created humid so that it is not dried out by the hot substances with which it interacts.

Avicenna goes on to describe the brain as, "soft and fatty," because it needs to be "resilient." In an atypical departure from Galenic teaching, Avicenna states that his opinion on the texture of the brain differs from that of the Greek anatomist. Galen had stated that the soft quality of the brain is to "allow it to assume diverse shapes during imaginations." However, Avicenna claims that the brain is soft because it contains fat, which, "is able to nourish gradually and conveniently the tenacious nerves." He proceeds to explain that the soft brain gives rise to certain harder nerves, which lack fat. Finally, Avicenna states that the softness of the brain, aids the, "rapid movement" of pneuma.

Avicenna differentiates the anterior part of the brain, which is softer, and the posterior part, which is harder. These two parts, he states, "are separated by a hard membrane," which folds onto a point (the tentorium). Avicenna explains that the anterior part of the brain is soft because of, "the sense organs, especially hearing and smell, arise from it."

"The majority of motor nerves arise from the posterior part of the brain, and it is from this part that arises the spinal cord," Avicenna states. Since these nerves are more "vigorous," they need to be associated with the harder portion of the brain. Avicenna explains that the soft tentorium, "a tent or a cloister," separates the harder and softer parts of the brain.

Avicenna describes the dura and its folds, which incorporate the cerebral venous system. He adds that, "beneath this folding of the membrane, and its most posterior part, is located the torcula, a place where blood empties into a vacuum, as into a reservoir." Several sinuses arise from the torcula for the purpose of, "propagating blood," after which it is integrated into the substance of the brain. "Subsequently, the veins absorb the blood and collect it into two veins," of Galen. Avicenna states that the dura is related to the pericrainium.

Avicenna describes briefly the olfactory nerves, which he says, "resemble breasts, and through which there is smell." He adds that they are unlike the texture of the brain but not as hard as nerves.

The meninges are described next. The arachnoid and pia, considered as a single membrane, are "contiguous with the brain substance," while the dura, "is thick and contiguous with the bone." The two serve as barriers so that the "brain does not come in contact with the substance of the bone, nor be damaged by it." Avicenna states the brain sometimes swells and may contact bone, as in the case of "shouting loudly." The meninges are

doubled so the dura, which contacts bone, does not touch the soft brain. Avicenna states that the dura also helps in "maintaining the position of the veins since they are integrated into the membrane." The deeper pia and arachnoid is closer to the brain, which "allows intimate access to the veins and arteries." Avicenna states that the dura "is nailed to the cranium by membranous ligaments arising from the thick membrane itself." The ligaments traverse the cranial sutures and are continuous the pericrainium.

Next, Avicenna describes the ventricles, which are, "three longitudinally cavities." He states that the anterior ventricles, "serve to aspirate the air, to dispose of the excesses, and to distribute the great majority of the sensory pneuma, and to operate the formation of ideas arising from internal perception." Alternatively, the posterior ventricle is involved with the spinal cord and "the great majority of the motor pneuma, and the operation of memory faculties." Avicenna describes in detail the size of the posterior ventricle and states it tapers towards the spinal cord, where it increases in "tenacity."

Avicenna calls the middle ventricle "a passage between the anterior and posterior ventricles, and as a corridor between them." He describes the shape and placement of the ventricle and states it allows "the anterior pneuma reaches the posterior pneuma, and through it things are stored in memory." Avicenna describes the quatrigerminal plate and the velum interpositum as "a roof with four pillars," which protects and supports the middle ventricle. He states that the union of ventricles is "the place where ideas are formed to the place where they are preserved, it is a location most suitable for cogitation and imagination." Avicenna adds that lesions in these areas affect memory, thought and imagination.

Avicenna claims that an extension of the meninges penetrates the inside of the ventricles and "carpets them." This allows the "psychic pneuma" to diffuse into the brain itself. He states that the pneuma is converted within the brain as follows: "as the pneuma reaches the brain in the anterior ventricle where it is cooked, it subsequently reaches the middle ventricle where it is cooked further, and the reaction is finally completed in the posterior ventricle." Such a reaction depends upon the "folds in the anterior portion of the ventricle" which have a "larger volume than in the posterior ventricle," because the pneuma decreases in volume following its alteration within the ventricles.

Avicenna notes that between the middle and posterior ventricles, "there is a place where the two great veins divide into branches intimate with the choroidal net inferiorly." In the separation of the branching veins is a "body of glandular character," which is in the "shape of a pine cone." Avicenna states that the head of the pineal gland separates the two internal cerebral veins, and its base "rests on the choroidal net."

Avicenna describes the coverings of the brain surrounding this middle ventricle as "the body of a worm" and assumes the form of a "vermis, with transverse folds, allowing the extension and contraction of this structure." He states that the vermis unites at "two oblong eminences of the brain, resembling two thighs, adjacent one onto another, and allowing a separation by a certain distance." Avicenna states that the vermis is connected to the "eminences," by ligaments. He adds that when the vermis is extended "it draws the two eminences into close contact, thereby occluding the canal between them." However, when the vermis is contracted "the two eminences separate from one another, opening the passage way." Avicenna states that the "two eminences are named the two

grapes." The "grapes" are connected to one another so as to better occlude the canal near them.

Avicenna notes that there are two "conduits" which "eliminate the excess from the brain." These are located in and near the middle ventricle. He adds that the posterior ventricle does have a conduit, because it is smaller and can share a conduit with the middle ventricle. The posterior ventricle is also "itself a conduit for the spinal cord, allowing some excesses to be expelled in that direction." He writes that the conduits form a "narrow funnel," the infundibulum, or "basin." The conduits lead to the pituitary gland which resembles, "compact sphere which is compressed in a superior to inferior direction into an ellipse." Avicenna states that the pituitary is "situated between the hard membrane and the canal of the palate." In the same area, a "spongy filter" contains conduits which lead towards the palate.

AVICENNA ON THE CRANIAL NERVES

Note: the following sections on neuroanatomy are condensed from the most recent English edition of the *Canon,* a translation directly from the original Arabic text, by Mazhar H. Shah. [27]

The third section of the *Canon's* chapter 5, *Organs—Nature & Variety*, contains a section on cranial nerves, which is comparable in length to Galen's passage. This section is preceded by a brief, 200 word "special discourse on the nerves," in which Avicenna asserts the primary role of nerves: to act as a liaison between the brain and the sensory and motor organs of the body. All nerves originate in the brain, according to Avicenna, including the spinal nerves, as the spinal cord itself is an extension of the brain. Avicenna then describes the special "protection" accorded to cranial nerves in their foramina, and attests that these nerves forge through bone in the most direct course rather than around it, "as the most direct course is also the shortest."

Avicenna begins his description of nerves with a brief statement of function, which he divides into direct and indirect. The direct functions include motor activity and sense perception. Indirect functions are to "give strength" to muscles and the whole body. Nerves also alert the brain of disease through sensing organ distention from *reeh,* or putrefied vapor.

The difference between cranial and spinal nerves is next discussed. Cranial nerves arise directly from the brain and "provide sensation and movement" to the head and internal organs. The vagus nerve's wandering track is mentioned and it is stated that sheaths, including the carotid, mediastinal and peritoneal, strengthen it on its long course. It is asserted

that sensory nerves are softer than motor nerves which arise from "the relatively harder hindbrain."

Avicenna faithfully reproduces the Galenic divisions, including the grossly correct relationship of various nerves to each other. Seven pairs of nerves are discussed. The olfactory bulbs' origin are described as two "nipple-like prominences." Avicenna notes that its function is the perception of smell.

The optic nerves are presented as the first pair of cranial nerves, arising near the olfactory bulbs and in the depth of forebrain ventricles. The optic nerves are described as "short and hollow" which cross at a chiasm shaped "like a crucifix." Each nerve is made of both crossed and uncrossed fibers. Three advantages are given to the partial decussation. First is that in the case of unilateral injury, "vital force" can be diverted to the opposite eye. Avicenna supports this idea by indicating that the pupillary response affects both eyes simultaneously. The second advantage is that the two visual images are said to overlap at the crossing to be perceived as one object. Double vision is caused by vital force not reaching the eyes in equal amount, as in the case of a squint. Third, the nerves are said to "support" each other. The second nerve described is the oculomotor nerve which was said to move the eye. It is described as soft and thicker near the brain because it receives no "support" from other nerves.

The third pair of nerves described includes the trigeminal and the sympathetic nerves. The first of this complex's four branches is said to pass through the foramen lacerum and supplies the diaphragm and the internal organs. The second branch emerges from the stylomastoid

foramen and joins the fifth nerve, or facial and auditory complex. The third branch traverses towards the eye but avoids the optic canal and passes through the superior orbital fissure. It subdivides into the ophthalmic, mandibular and maxillary nerves. Each nerve innervation is briefly noted. The lingual is called a "fine nerve" to compensate for a hard tongue, while the softer eye is supplied by thicker nerves.

The fourth nerve described is the sensory branch of the trigeminal, which is "smaller and harder" than other branches of the trigeminal because it supplies sensation to the softer palate and is responsible for taste.

The fifth nerve includes the facial and auditory branches. The facial branch follows the course of the third nerve, providing movement to muscles of the cheeks and face. The temporal branch of the facial nerve is contrasted to the optic nerve. The temporal is hard but thin, while the optic is soft and thick due to the texture of the organs each nerve innervates. The "nerve for hearing" is described as especially hard to balance its requirement of contact with air, the lightest of substances.

The sixth nerve is the glossopharyngeal, vagus and accessory complex which is described as arising through rootlets near the origin of the fifth (facial-acoustic) nerve before forming a proper trunk and exiting through its own foramen near the base of the lambdoid suture (jugular foramen). After passing through the jugular foramen it separates into three branches. The first branch described is the glossopharyngeal and travels to the muscles of the pharynx and the root of the tongue. The second supplies the muscles of the shoulder. The vagus is said to leave the skull through the "carotid foramen" and "supply the viscera." The recurrent laryngeal is described as it courses around the aorta. The vagus is said to join the third nerve (trigeminal, facial motor) to supply the

diaphragm, visceral peritoneum and flat iliac muscles. Branches of the glossopharyngeal, vagus and accessory complex are accurately described, including the recurrent nerve as it courses around the aorta and its asymmetry is correctly noted.

The seventh cranial nerve is the hypoglossal, noted as moving the muscles of the tongue while taste is mediated by a separate nerve previously discussed.

AVICENNA ON THE SPINAL NERVES

The *Canon's* Book I, chapter 5, sub-chapter *Muscles*, contains a section entitled *General Description of Nerves, Muscles, Tendons and Ligaments.* [27] Avicenna discusses voluntary movement which occurs when the brain sends its "endowed energy" to the muscles by way of the nerves. He describes the branching into progressively smaller-diameter nerves which need to be protected as they pass through foramina. Protection is provided by a covering of fibrous tissue which houses the nerves "like a central pillar." It is noted that muscles contract against tendons, made of fibrous and nervous tissue, to pull bones in order to produce flexion.

The next section is *Cervical Nerves,* where eight pairs of cervical nerves are described. The cervical nerves are said to emerge from foramen above their respective vertebrae. Nerves supplying muscles to the neck, back and their cutaneous branches are described. The joining of the first four pairs of nerves to become the cervical plexus is described. The roots of the brachial plexus and phrenic nerve are briefly described. Special attention is paid to the innervation of the diaphragm and its optimal arrangement of nerves arising from above the mediastinum and innervating the center of the muscle.

In the following sections, Avicenna proceeds down the spinal cord. The thoracic nerves are described and stated that each pair exits at foramen below its respective vertebrae. Relations to the brachial plexus are given. Innervation of thoracic and intercostal muscles are noted. The lumbar and sacral plexii are noted. The close relation of the vagus is noted. The nerves which supply the great muscles of the leg are briefly named. The

nerves of the sacrum and coccyx are summarized as joining the lumbar nerves to form the sacral plexus. The remaining nerves innervate the penis, bladder, uterus and muscles arising from the sacrum.

AVICENNA ON THE SKULL AND VERTEBRAE

Avicenna's discourse on the skull and vertebrae are contained in Chapter 5, *Organs—Nature & Variety*. His first sub-chapter is entitled *Bones*, and begins with a section called *General Description of Bones and Joints*. [27] Although Avicenna himself did not use chapter subtitles, the translator's headings will be used here for the sake of clarity.

Avicenna discusses the functions of bones, including providing a foundation" for muscles and "covering and protection to various parts." Some bones such as the spinous processes "afford protection" against injuries, friction and shock while others, such as the sesamoid, "fill spaces." The substance of bones is described and attention paid to the "central canal" filled with marrow which supplies nutrition. It is noted that skull bones have sinuses since these bones are "required to be light". The ethmoid bone has an aperture to "facilitate the inhalation of odors" and "eliminate excrement from the brain."

Next, joints are defined as articulations of bones with varying amount of space filled with cartilage. Joints are classified according to freedom of movement. Diarthrosis are "freely movable." The wrist is classified as a "hinge" joint. The carpal and metacarpal joints are partially movable and the sternum is a fixed joint. "Impacted joints" such as teeth are placed tightly in the jaw allow no movement. Sutures are noted. Rotary joints such as between the radius and ulna are described. The upper lumbar vertebrae are "partially mobile" and lower are "completely immobile."

Avicenna's second section is entitled *The Skull and its Functions*. He states the purpose of the skull is to protect the brain "like a shield." The

skull's multiple bones provide increased protection against traumatic injuries as well as to provide variable thickness according to function, i.e., allowing the passage of nerves, "escape of thick vapors" and passage of arteries and veins.

The author describes the shape as ovoid which increases volume and distributes shock of impact. He states that the skull has three "true" and two "false" sutures. True are the coronal, sagittal and the lambdoid. False are the squamosal sutures which "do not penetrate the bone but overlap like fish scales."

Further defined are three types of crainiosynostoses caused by the absence of either coronal, sagittal or lambdoid sutures and each is described by their lack of relative prominences. In these descriptions Avicenna pays homage to Galen and Hippocrates whom, he says, correctly classified skull shapes into one normal and three abnormal.

The next section is called *Other Bones of Skull.* The "five bones of the skull" are described, beginning with the two parietal bones and the others in relation to these two. It is noted that the bones at the sides are stronger because they are exposed to more injury while those of the vault are "spongy" in order to allow for escaping vapors. Frontal bones and the corresponding sutures are described, noting the "stone-like" quality of the temporal bone. The occipital bone is described without naming it. The sphenoid bone is said to have wings and its function is to "carry the weight of the skull."

Avicenna proceeds to describe *Bones of Jaws and Nose.* The upper jaw is described as is its relation to the frontal bone and temporal and sphenoid bones. The location of sutures is noted. The description of small bones is added, such as the ethmoid and nasal bones without naming them.

Avicenna states the function of the nose is to inhale large quantities of air, release air from the larynx to aid in the "utterance of syllables," and provide a route for the elimination of secretions from the head. The nasal bones are described and the relation to the frontal bone is given. Also noted is the cartilaginous nasal septum and the soft palate, which have advantages of being able to expand fully and expel smoke and other irritating vapors. Avicenna concludes by describing the lower jaw, its midline suture and the ligamentous attachment to the skull.

Avicenna begins his discussion of the vertebrae with a section entitled *Function of the Vertebral Column*. He states there are four functions of the vertebral column. First, is to allow the passage of the spinal cord. Second is to give protection to the organs. Third is to provide a foundation to the other bones. Fourth is to establish a pillar for stability during movements.

Next, Avicenna discusses the bones of the back in *Vertebrae*. The vertebrae are defined as bones with a central foramen and four to eight articular processes which attach to the facets of other vertebrae. Avicenna notes the presence of longitudinal and transverse ligaments. Spinous processes are said to provide protection against shocks. The author notes the presence of foramina for the passage of nerves and blood vessels. The vertebral column is made of multiple bones to allow some freedom of movement.

Avicenna moves on to the next section, entitled *Functions of Neck and Cervical Vertebrae*. The purpose of the neck is said to accommodate the trachea. The increasing diameter of the vertebral column is noted. Cervical vertebrae are thinner and weaker than others and have been

"compensated" by additional coverings of muscles, blood vessels and nerves.

Seven cervical vertebrae with eleven processes and a foramen transversarium are described. Avicenna notes the difference in the first two vertebrae and states right to left movement occurs between the skull and the atlas while forward and backward movement occurs at the atlanto-axial joint. He describes the odontoid process and states it prevents dislocation. The first vertebra is described in detail and the absence of a spinous process is noted. The path of spinal nerves is mentioned.

Avicenna notes the ligamentous attachments of the odontoid to the atlas. These have a certain degree of laxity due to the required freedom of movement.

Next, Avicenna discusses *Thoracic Vertebrae and Their Functions.* Avicenna notes that the ribs are attached to the vertebrae at their respective processes. He states that the processes are larger and in closer proximity to vital organs, such as the heart. He describes articulations of ribs and their corresponding processes of other vertebrae. The author notes the lumbar vertebrae are longer and stronger than others in order to carry increased weight. Articular processes are likewise larger having to account for increased width and the attachment of the diaphragm. The vertebral canal is increasingly narrow causing the spinal cord to end prematurely, allowing only the passage of lumbar and sacral nerves. Lumbar vertebrae are briefly described, along with their processes. Three vertebrae of the sacrum are noted and said to be similar to lumbar vertebrae. The coccyx is said to be made of three cartilaginous vertebrae which have intervertebral foramina and one coccygeal nerve.

Avicenna ends with a section entitled *Final Description of the Functions of the Vertebral Column*. It is stated that the cylindrical shape of the vertebral column withstands traumatic injury. The spinous processes are projected downward. Movement of the spine is facilitated by articular processes which face downward.

LIFE AND TIMES OF GALEN

The second century A.D. was the golden age of Roman science due to the astounding activities of Ptolemy and Galen The two giants were of Greek origin and their masterpieces were written in the Greek language. Their important works were not translated into Latin until many years following their deaths. As opposed to science, all the classics of literature, such as *The Iliad, Odyssey* and *Aeneid,* had already been written in Latin. Thus, the Empire was bilingual; Greek was the language of science and philosophy, Latin that of literature, administration and business. [25]

Galen's home was Pergamon, fifteen miles inland on the mainland of what was called Asia Minor. At that time, the Egyptian city Alexandria was the center of Hellenistic science and Pergamon was one of its main rivals. The Galen's home contained an acropolis 1000 feet above a fertile plain near the confluence of three rivers. An early king of Pergamon wished that his city to emulate Alexandria and Rhodes. He intrusted the planning of the capital was to a Greek architect who made sure every public building would appear glorious. Pergamon became one of the most beautiful Hellenistic cities. Its library was so well endowed that rival kings forbade the exporting of papyrus for Pergamon's books. Local writers countered by developing a different kind of writing material, processing the skins of animals, called *charta pergamena,* or parchment, which bore the city's name and was critical in the development of the codex or book. Pergamon's famous library had been presented whole to Cleopatra in 40 B.C. by Mark Antony.[25]

The most significant feature of Pergamon was the existence of a famous Asclepieion, or medical temple, across the river Selinus. The

Aesclepieion was at once a religious sanctuary, a sanatorium and theater. During Galen's time it was one of the great centers of pilgrimage of the Roman world. The citizens of the empire believed that the temple at Pergamon was a place of special, almost divine, restorative powers. Interestingly, Galen was so obsessed by Asclepius, a god of health, that he paid no attention to Jesus Christ and the evangelists who occupied Pergamon and made it one of the early seats of Christianity. [25]

Galen was born in Pergamon in the year 130 A.D. During his lifetime, several Roman emperors ruled, including, Antonines, Antoninus Pius, Marcus Aurelius and the despotic Commodus. Galen's was a distinguished family that lived on an estate outside of the city. His father, Nicon, was a wealth architect who took a deep interest in his son's education, but his mother was a difficult and quarrelsome women, who Galen compared to the irascible Xanthippe, wife of Socrates. [25]

Galen was educated in the four leading schools of philosophy, Platonism, Aristotelianism, Stoicism, and Epicureanism. He studied under Satyros, a famous anatomist, at the Asclepieion for four years. After his father's death, Galen worked in first in Smyrna and then in Alexandria. He wrote a treatise in three books on the movements of the lungs and thorax. When he returned to Pergamon, Galen was appointed physician to the gladiators for about four years.

About the year 162 A.D. Galen traveled to Rome where he rented a large house and began practicing as a physician. After some controversial dealings, Galen returned to Pergamon. A war against the Germans led Galen to Aquileia, in the Northern Adriatic, as a military surgeon. His fame was so great by then that he was sent back to Rome about 170 A.D., by Emperor Marcus Aurelius, to care for his ailing son. Galen stayed in

Rome until around 192 A.D. when he returned once again to his hometown where stayed until his death at the age of seventy. His final years were dedicated to meditation and writing.

Galen's education may be divided into three parts: the primary and secondary education at home from 130 to 144 A.D.; the philosophical education, or "undergraduate" years, in Pergamon, 144-46 A.D.; and finally the medical education in Pergamon and elsewhere, 147-58 A.D. During this era there were four common schools of philosophy, or sects, to which Galen had been exposed. Likewise, physicians were divided into six medical sects, three were considered ancient and three, "modern."

The most ancient medical sect of Galen's time belonged to the Hippocratics. Its adherents believed all medical knowledge existed solely in the Hippocratic corpus. Another was the Dogmatic sect which emerged under Aristotelian influences and attempted to reconcile the physiological theories of the Hippocrates with the scientific doctrines of Aristotle. The third group was the Empirical sect, which was founded at the anatomical school of Alexandria. Its practice was based on clinical observations and history taking, but also relied heavily on potions and verged on charlatanism. [25]

The oldest and most important of the "modern" sects was Methodism, which was characterized by a belief in solidism, the equivalent of the atomic hypothesis. Solidism was opposed to humoralism, the theory of the humors developed by the Hippocratics and later by Galen. It is interesting that the ancient solidists had recognized the three main states of matter: solid, liquid and gas, and applied the distinction to physiology. Galen had much contact with this popular sect, but was strongly opposed to its doctrines. [25]

The remaining sects were Pneumatism and Eclecticism, of which Galen was aware but only somewhat supportive. The Pneumatists held the belief that the physiological significance of air and breathing was of primary importance to life. During Galen's time most physicians belong to one sect or another from schooling but tended to combine elements of various dogmas to suit their personal tastes. The Eclectic sect, in particular, tried to harmonize the teachings of others. In his writings, Galen criticized most of the sects of his time, but his most vehement words were saved for the Methodists. Galen himself never claimed to belong to one group or another and expressed his assertions as unique. [25]

Galen's writings reveal an abundant clinical knowledge, and the Galenic corpus contains a large amount of clinical cases. He attached considerable importance to diet and hygiene. He insisted upon physical exercise. Galen had a wide experience of surgery from treating gladiators. He also wrote of operating on nasal polyps, goiters, cancers, fibrous tumors and lipomas. He gave up surgery in Rome because of a decree which did not allow physicians to practice both medicine and surgery. He was known to be honest and sincere but egotistic, vain, complacent, irritable and jealous. [25]

During the Hellenistic and Roman period paganism had become modified. Few accepted the old myths, but mysteries and rites were popular. The highest religious ideals were astrological. Planets were identified with the gods. [25] Galen was a pious monotheist, who was anxious to keep in touch with the gods and obtain their favor. He strongly believed in the divination of dreams. He divided dreams into their three causes: physical, psychological, and divine. He claimed to have often been inspired by the gods in a dream. For example, he performed a minor

operation upon himself that he had imagined in a dream. He believed that Asclepius ordered his father to educate him in medicine. Divination of dreams was an accepted guide for diagnosis and therapeutics. [25]

Galen most certainly had knowledge of Jews and Christians but probably did not fraternize with them. Although he was Pagan, Galen endeared himself to Jewish, Muslim and Christian theologians by his teleological views and his opposition to atomism and evolution. Galen was the man who proved the theologians' faith to be scientifically sound.

Galen's career was somewhat of a paradox. He began his studies as one of the few ancients who appreciated and employed the scientific method. In this way he tried to be tolerant, impartial and open-minded. Yet his later writings began to sound like theology. He had become a dogmatic mystic. His fame established him both as the leader of the experimental method and its application to medicine as well as a spiritual guide. For nine centuries he was the supreme prophet of medical dogma, then he was joined by Avicenna, and they ruled together until the seventeenth century. [25]

WRITINGS OF GALEN

At the age of sixty-seven Galen wrote two treatises dealing "with his own books," *De libris propriis*, which constitute one of the first autobiographies in world literature. It is from these essays that much of the chronology and titles of Galen's many works are known since many of his original texts were lost when the great libraries of Alexandria and Persia were destroyed by fire. In addition to medical and anatomical studies, Galen wrote philosophic treatises, the bulk of which dealt with the opinions of Hippocrates and Plato. He wrote a tract on the Hippocratic maxim, "the best physician must also be a philosopher." He was also a medical historian and wrote two dictionaries. Galen's first anatomical essay was an account of the dissection of the womb for midwives. He was a prolific writer and compiled many texts in medicine. Galen's early education had been in philosophy, thus writing came easily to the anatomist.

The technique of anatomical study was more than four centuries old by the time of Galen. He had learned anatomy from his teacher, Satyros, who also taught him surgery and medicine. Because human dissections were frowned upon in Pergamon and other Greek cities, Galen's knowledge of human anatomy was restricted to skeletons and his information regarding soft organs was derived from the bodies of animals, namely pigs, sheep, oxen, cats, dogs, horses, lions, wolves, and at least one elephant. His favorite material was the Barbary ape, a type of macaque monkey which now flourishes in North Africa. The early Roman and Greek anatomists took for granted the similarity of animal and human

bodies. [25] Galen probably acquired additional knowledge of human anatomy through his surgical work with gladiators.

One of the most important of the many Galenic works devoted to anatomy is *De anatomicis administrationibus,* which is a detailed guide to the dissection of animal bodies, chiefly monkeys. In it, Galen goes through the anatomy of the entire body, from central nervous system, to internal organs and the musculoskeletal system. He elaborates upon techniques of dissection, minute points of anatomy and the differences between his work and that of his contemporaries. The first part of this discourse, Books 1 to 9, was well known in Europe during the Middle Ages. The second half, Books 9 to 15, was completely unknown to Western readers until 1906 when the Arabic version was translated into German. [25]

Some of Galen's other anatomical treatises are "On the dissection of veins and arteries," "Of bones and tendons," "On muscular motion," "On the utility of respiration, " "On the natural faculties" and the famous, *De usu partium corporis humani,* or "On the uses of human body parts."

Although admirable, Galen's work contained occasional errors. He did not differentiate between nerves and tendons. Galen noted that nerves innervated muscles, but concluded that they exited and became the whitish cords which attached to bone. Thus, he called both the nerve and tendon *neuron.*

Considering his limitations, Galen made remarkable contributions, especially in the area of experimental physiology. Among Galen's observations is that arteries contain and carry blood. He established that the recurrent laryngeal nerve is a link between the brain and voice production. The anatomist disproved that the voice comes from the heart by means of a famous operation to transsect the recurrent laryngeal nerve.

Galen also showed that the spinal cord is significantly unlike bone marrow. Through a series of cervical and thoracic spinal sections in pigs, he illustrated the various types of paralysis which are related to particular levels of the spinal cord.

Galen recognized the need for experimentation and observation. He claimed that performing one's own dissections was the "path towards truth," and, in frequent passages, he urged his readers to take up a scalpel if they doubted his descriptions. Galen's most severe criticisms of his rivals were that they did not perform their own dissections and experiments. However, Galen eventually allowed himself to succumb to what he condemned in others as he became dogmatic and judgmental. In his later books, he began to expound comprehensive physiologic theories which reached beyond the data he had personally collected. [25]

An example of one of Galen's limitations is his pneumatic theory. Galen asserted that each of the major organs were dominated by a special spirit or *pneuma*. The spirit was a vapor rising from the blood and controlling various functions such as growth, nutrition and reproduction. Vital spirit, for instance, originated from the heart and was transmitted through arteries. This theory was strongly held by physicians and scientists up until the time of the seventeenth century when William Harvey showed the directionality of blood flow.

Another of Galen's erroneous theories was that of the temperaments, which was based on the four humors. Humoral theory went back to the fifth century B.C. when Empedocles expounded the concept of the four elements of earth, water, air and fire. By the time of Hippocrates, the theory had a physiologic parallel in the four qualities of dry, wet, cold, and hot, and later the four humors, blood, yellow bile, black bile, and phlegm.

The concept that the proper mixture of the four humors produced health has been ascribed to Hippocrates' son-in-law, Polybos. Galen's idea of the four temperaments was a restatement of the old theory of the elements. He suggested that personality, or temperament, is related to the mixture of the humors and resulted in only four types of dispositions, sanguine, choleric, melancholic and phlegmatic. [25]

Galen was a highly religious man and his writings reflect his beliefs. He was first to praise the Creator in a scientific way. In his *De usu partium corporis humani*, Galen contemplates the marvels of the organization and complexity of the body. He concludes that such beauty and organization could only be the result of a divine plan or design. Galen's doctrine of teleology states that everything was created for a definite purpose. He strenuously opposed earlier anatomists who taught that the function helped create the part.

Yet Galen was essentially a pagan. In addition to the Creator, he accepted the secondary gods and heroes such as Asclepius, the god of health and medicine. Galen argued that God, or the Creator, existed, based on the beauty of design of nature. [25] Throughout his many works, one feels the author's appreciation of natural organization, the elegance of which Galen atrongly imparts to his readers.

SUMMARY OF GALEN'S NEUROANATOMY

GALEN ON THE BRAIN

The significant collection of Galen's neuroanatomy appears in his *De anatomicis administrationibus*. Book IX of this work is entitled *On the Brain* and divided into fourteen chapters. As noted above, the first five are available as translations directly from the Greek and the second portion of the book was translated from Arabic and Latin texts only in the twentieth century. [13]

In the initial chapter, Galen begins with a statement of purpose. He states that dissecting the brain and spinal cord of a dead specimen is relevant training for the student and should precede any operation on living creatures. [30]

Galen begins his discussion with the skull and the "meninx" or thick, hard membrane. Galen suggests that his reader use ox brains, which were commonly available from butchers, and discusses various types of instruments which are of most profitable use. [30]

Galen observes that the dura mater appears much thicker in the midline and dips into the median suture. He also notes that the dura penetrates the brain at the lambdoid suture where two major veins converge.

Galen states that the front of the brain is much larger than the back. He notes the presence of another major vein which runs along the surface of the brain. Galen writes that as the blood vessels traverse the skull they enter a space where the dura mater is doubled.

The author goes on to explain how to strip the brain of its meninx using a thin wooden scalpel. He states that one should place the scalpel into

the space where two veins meet "in the region that Herophilus called the torcular." Galen explains how to penetrate the venous sinus and make an incision to cut away the large and small veins. [30]

In chapter two, Galen observes the delicate veins issuing out of the venous sinuses, some of which travel to the surface of the brain, others to the cerebellum. Galen describes the falx cerebri and its relationship to the venous sinuses. He discusses the course of the great cerebral vein and explains how to divide the brain along its folds, the falx and the tentorium, to expose the origins of the venous system. Galen describes the "delicate meninx" or pia mater and notes that Hippocrates called this the "meninges." He says the pia mater embraces the brain and accompanies it into the depths, but the dura mater remains superficial. [30]

Galen begins to discuss techniques of dissecting the substance of the brain in chapter three. He explains how to bisect the brain along the falx cerebri and dissect away the great cerebral vein and the inferior longitudinal sinus. He states that there remains a "natural hollow" from which the venous sinuses were removed. Galen says this space "receives from the overlying and surrounding tissues incompletely concocted nutriment." Galen goes on to describe the difference in appearance of the corpus callosum to the brain substance. He then leads the dissection to the "chorioid plexuses," called "chorioid concatenation" by other anatomists. Galen states it is a "plexus of veins and arteries held together by delicate membranes." He says the veins of the ventricles branch from the venous sinuses while the arteries come from the carotids. Galen describes the ventricles and the delicate, translucent septum pellucidum. He reaches the pineal body, which is "hidden in a cleft of veins." [30]

In chapter four Galen describes the third ventricle and its relationship to the lateral ventricles along with the interventricular foramina. Galen notes the presence of associated veins. He states the septum pellucidum is extremely soft and delicate and unable to support overlying structures. Galen describes the duct at the bottom of the third ventricle and says it transmits waste products.

At this point Galen criticizes those anatomists who are unable to properly expose "the parts under discussion" and fail to observe the "third ventricle between the two anterior ventricles with the fourth behind it." Galen notes a duct leading to the cerebellum, the infundibulum and the pineal gland. [30]

In the next chapter Galen describes two pair of "gently rounded tissues," the superior and inferior colliculi. He uses the term *glouta,* buttocks or nates, in discussing the colliculi and states that some authors call them *didymia* or twins and others call them *orcheis* or testicles. Galen describes the cerebral aqueduct and notes its position. He calls the vermis the "vermiform process" and says it is "shaped like the worm that grows in wood." Galen states it reaches from the pineal gland to the back of the cerebellum. [30]

The following sections were taken from translations of *De anatomicis administrationibus* that were made from Arabic and Latin. Galen describes how to remove the vermis which "covers the passage" between the third and fourth ventricles. He instructs the listener to place a probe through the cerebral aqueduct and pass it into the posterior or fourth ventricle. Galen notes that the passage continues into the "spinal marrow" and that the continuation of this passage is unlike the ducts between the third and fourth ventricles in that it is only covered by a membrane and not

a "body" such as the cerebellum. Galen then opens the fourth ventricle and withdraws the pineal body which, he states, is made of "spongy flesh." [13]

In the next chapter, Galen describes the posterior horns of the two "anterior," or lateral, ventricles. He continues to explain how the lateral ventricles are connected to the third via ducts. Galen notes that the anterior horns of the lateral ventricles, what he calls the "nasal horns," are wider than the rest of the ventricles. He states that in an emaciated animal the brain is harder and more desiccated than in a healthy animal. Next, Galen discusses the lateral geniculate body and states it joins the "two nerves of sight" or optic nerves. Galen describes the olfactory bulbs and calls them the "outgrowths of the two anterior ventricles" which stretch toward the nasal cavities. Here, Galen contradicts a statement that he makes in *De usu*, that the optic nerves originate in the anterior ventricles. He continues to describe the cribiform plate. Galen makes a long statement on the difficulty of observing the details of the infundibular recess, which, he says, is an orifice for an effluent which is the consistency of "muck." [13]

In the next chapter Galen states that the optic nerves and chiasm join in the shape of the Greek letter chi, which looks like the letter X. He says that where the carotid arteries join at the base of the brain is a "pool" or "cistern" which is the sella turcica. Lying below this pool is "flabby spongy flesh, similar to a lupine bean," which is the pituitary gland. Galen notes that "innumerable arteries are entwined" about the pituitary gland. [13]

GALEN ON THE CRANIAL NERVES

The ninth chapter of Book IX, *On the Brain*, contains a relatively brief selection (about 1000 words) regarding the cranial nerves. [13] Galen's text was much like a dissection manual and in this section he describes the base of the brain and proceeds to evaluate seven pairs of cranial nerves.

Galen states that the olfactory bulb is a "nipple" which leads to the nose and lies medial to the optic nerve. He asserts that the optic nerve is the first cranial nerve and is "softer and larger" than any of the nerves because it serves the "most subtle, complex and purest of the" senses. The second nerve Galen lists controls eye movement is probably the oculomotor nerve. It is called "harder and thinner" than the optic nerve since it innervates muscles.

Third, Galen describes the trigeminal motor root and the facial nerve which are "slender" and originate in the "hinder part of the brain's base." Fourth is the sensory branch of the trigeminal. Fifth is the complex of the facial and vestibulocochlear nerves.

At this point Galen digresses into an account of how his own teachings about the cranial nerves and their foramina is superior to his contemporaries' who did not perform dissections themselves. Sixth, Galen lists the glossopharyngeal, vagus and accessory nerves together. Finally, Galen's seventh cranial nerve is the hypoglossal. [13]

GALEN ON THE SKULL AND VERTEBRAE

General Comments

Galen's discussion of the skull, skeleton and the bones of the body is found in his uncharacteristically concise, *De ossibus ad tirones,* or "On the Bones for Novices." In it, Galen first defines the skeleton as the "whole structure of the bones in the human body linked together." He states there are two kinds of linkages, first is the joint, which is a juxtaposition and next is the symphysis, a union. He further explains that there are two types of joints, diarthrosis and synarthrosis which differ in their degree of mobility. Galen subdivides diarthrosis in three forms, enarthrosis, arthrodia and ginglymus. The types of synarthrosis are sutures, harmonia and engomphosis.

Galen defines three types of connective tissue, what he calls neura. The first he calls "voluntary" and states they originate from the brain and spinal cord. The second are acutally tendons and arise from muscles. Finally, he states that the ligaments attach to bones. [15], [21]

The Skull

Galen describes the skull or "cranium." He states it has the shape of a prolongated sphere and has three sutures, the coronal, the lambdoid and the transverse. The joining of these sutures can have natural variations. Galen states that the "bregma" or parietal bone is joined at its superior aspect by a "squamosal suture." He says the lower limits of the lambdoid suture extend to the petrous portions of the temporal bone. [15], [21]

Galen states that there is a total of six bones in the head, not counting the sphenoid. He lists the bregma, or parietals, the temporals, the occipital and the frontal. Galen describes the sutures of each bone. He says the parietals are the most porous and weak of the bones, the occipitals are the densest and strongest, and the frontal is between the two. The temporals are "multiform," and its parts include the petrous portion, the styloid, the mastoid and finally, the temple. Galen describes the zygoma, its arch and the edge of the eyebrow at the small, outer canthus.

Galen discusses the bones and sutures of the upper jaw. He notes the suture beneath the zygomatic arch and its relationship to the optic foramen. The maxilla is described and its four sutures. Galen notes the different types of teeth that extend from this bone. [15], [21]

Galen describes the bones of the nose and midline sutures which descend into it. He adds descriptions of the bones of the palate. Galen proceeds to mention that the numbering of the bones of the upper jaw is a matter of dispute, especially regarding the number of bones in the nose and palate. He concludes that, in his opinion, there are fifteen bones.

Galen discusses the teeth, of which there are sixteen in each jaw. He names the incisors, the canine and the molars. Galen gives an account of the way in which each type of tooth grinds or chews food. He notes that all teeth have neura which connect them to the brain.

Galen states that the lower jaw bone is joined in the midline by a suture and its "knuckle-shaped" condyloid or extension fits into a socket under the mastoid process. [15], [21]

Vertebral Column

Galen writes that there are twenty-four vertebrae divided into the neck, back, flank, and sacrum. There are seven cervical vertebrae, twelve in the back and five in the flank.

Galen states that the first two vertebrae of the neck are joined by a powerful ligament to the other vertebrae. He claims that the vertebrae are joined to each other by the membrane of the two meninges of the spinal cord on the outside, filling in the interstices between the vertebrae. The head, Galen states, has two types of movements. Nodding back and forth is accomplished by movement linked to the odontoid of the second vertebra. Side to side movement is effected by the first vertebra with the condyles of the head. Galen notes the presence of an anterior ligament. He says the first vertebrae is broad and delicate, the second is thinner, but sturdier. He explains that the vertebrae become progressively thicker as they move inferiorly because the spinal cord becomes more attenuated. All the vertebrae except the first have a posterior spine. The first six cervical vertebrae have perforated transverse processes. The bodies of these have a downward slanting.

Galen states that twelve is the normal number of thoracic vertebrae. Their transverse processes are very large because they articulate with the ribs. The lumbar vertebrae are five in number and are the largest and thickest of all. Their processes tend upward. He explains that the lumbar vertebrae have foramina without an ordered arrangement into which veins grow. [15], [21]

Galen asserts that the sacrum is analogous to the vertebrae because it receives downward processes. Its transverse processes are large and broad and have a "hollow" into which the iliac bones attach. The sacrum consists

of three portions and a fourth coccyx. It allows passage for three pairs of nerves. The coccyx consists of three parts which are mostly cartilaginous. [15], [21]

NEUROANATOMICAL DISCOURSE OF AVICENNA AND GALEN

The most apparent difference between the neuroanatomical descriptions found in Avicenna's *Canon of Medicine* and Galen's "On anatomical procedures" is the style of presentation. Galen's work is fundamentally a dissection manual where he presents the practical points of anatomical study. Galen discusses various instruments for removing layers of skins and bone, offers differences of opinion among himself and other anatomists, criticizes his rivals,and explains methods of dissections along with presenting detailed descriptions of the various organs and anatomical structures under scrutiny. Galen's writing is, above all, conversational, verbose, self-referential and somewhat disorganized. He skips from organ to organ as an instructor in an anatomy lab would present the various parts which come under his view. One can easily imagine Galen standing at the dissection table, lecturing to his students on the different types of scalpels which are most useful for cutting, presenting the technique for exposing an organ and finally holding it up to the class, noting the texture, color and its associated structures.

Avicenna's descriptions of neuroanatomy are more concise and organized than those of Galen. Avicenna writes a comprehensive textbook which seems abstracted from manuals, as opposed to writing a text on the techniques of dissection. Avicenna presents the anatomy of the brain as well as its associated structures using more precise language and does not criticize other anatomists or offer advice on how to perform actual dissections and surgery. He is more likely to discuss various aspects of physiology while presenting neuroanatomy. He often goes into

explanations of the purpose of certain structures within the context of his humoral theory.

An examination of specific discussions on the brain, cranial nerves, skull and vertebral column is illuminating with regard to the Galenic tradition in Avicenna's writing as well as unique interpretations and contributions.

COMPARISON OF THE BRAIN

The first chapter of Galen's selection on the brain is a discussion of instruments, choice of material and techniques. He describes structures in sequence from most superficial to deep. Galen begins with the gross appearance, saying, "the front and back parts of the brain differ, the front being much greater." He explains how to remove the greater parts of the skull. Galen goes on to present the superficial veins within the dura.

Avicenna, on the other hand, begins with a more theoretical discussion. He concisely describes the entire structure of the central nervous system, organized into several categories. He is, in effect, presenting a table of contents for the anatomy that follows. He writes that the anatomy of the brain consists of an "envelope," a "medullary substance," "internal cavities filled with pneuma," and nerves branching from the brain.

Avicenna then launches into a discussion of the texture of the brain. He states it is "cold and humid." He explains that imagination, thought, memory and pneuma itself, is hot. Therefore the brain needs to be balanced by its own innate coldness. He also explains that the brain is soft so that its high fat content can support the many nerves which it feeds. The discussion is an example of his physiologic scheme which is based upon a theory of the temperaments. The amount of heat with which the brain has been innately endowed is related to Avicenna's ideas about the hierarchy of human parts, organized according to the varying amounts of qualities which they possess. Avicenna can easily jump from the anatomy of the brain to its physiology. Galen, however, seems to be restricted to technique, especially in "On anatomical procedures."

A major theme of Avicenna's in the discussion of the nervous system is the consistency of organs. He states that the brain is "soft," a quality which offers it certain advantages. He writes, "a hard substance cannot produce nourishment onto a softer substance, while a softer substance can." Avicenna had stated that one of the functions of the fat in the brain is to provide sustenance for the nerves which emerge from it. He describes the nerves and states that they "must arise soft and gradually acquire tenacity, while maintaining flexibility, making it necessary for their origin to be a supple and fatty substance." In Avicenna's opinion, the consistency of one organ must be matched and balanced by the qualities of its counterpart. He also draws conclusions about how the softness of the brain relates to its various functions. Avicenna states "the anterior of the brain is soft, since the majority of nerves and sense organs especially hearing and smell arise from it." Consistency and function were thought to be two interrelated qualities. Avicenna suggests that the teleology of experiencing sensations is an important factor in classifying sense organs and understanding the structural characteristics of sensory apparatus. He states, "vigorous nerves and motor nerves arise from this posterior part of the brain, its substance must be harder than that which is required for sensory organs." There was thought to be a difference between motor and sensory nerves which could be subjectively examined and measured. Interestingly, not only the nerves have varying consistencies, but the portion of the brain which those nerves innervate, have a similar degree of softness. For Avicenna, purpose was intimately associated with consistency and texture.

Galen's writing belies a similar understanding of the consistency of nerves relating to the function and structure of motor and sensory organs. In his descriptions of the brain, he explains that certain nerves have relative

degrees of hardness, depending upon the organ or muscle they innervate (see below, Comparison of Cranial Nerves). However, in his discussion of the substance of the brain itself, Galen does not point out any differences in texture or consistency between what was thought to be motor versus sensory structures. His physiology is more practical, less theoretical or abstract than Avicenna's. Galen seems to be more interested in describing structures and the innervation of organs, as opposed to presenting a unified theory of neuroanatomical function.

Chapter 12 of Book IX of Galen's "On anatomical procedures" is subtitled *Experiments in Brain Surgery.* After a lengthy discourse on the techniques involved in exposing the brain in living creatures, Galen describes certain experiments which can be performed to illustrate the relationship between a specific cerebral structure and the action of a muscle or set of muscles. He describes how to remove the cranium and raise the dura from the surface of the brain. Once the "three parts of the meninx," or meninges, have been removed, Galen asks the reader/student to "make an inspection and ascertain for yourself whether the animal is deprived of respiration, voice, movement or sensation." He states that when the exposure is performed in warm air, the animal loses vital functions quickly. However, if the air is cold, the "animal remains for a certain length of time unconscious, and then expires." It is interesting that Galen noticed that tissue damage is related to the thermal environment and that some degree of cerebral protection is provided by low temperatures.

Galen goes on to perform several experiments on the brain itself. He first shows that one can induce a stupor by pressing on certain cerebral sites. Galen states, "should the brain be compressed on both of the two anterior ventricles, then the degree of stupor is slight." However, he says

that deeper state of obtundation is achieved when the middle ventricular area is compressed and the animal falls into a coma when "one presses down upon that ventricle which is found in the part of the brain lying at the nape of the neck." Galen explains that these procedures produce reversible stupor, while cutting into the ventricles cause permanent coma. He also discusses the effects of cerebral compression and incision upon ocular responses, particularly, blinking. Galen states that in the event of compression in the most posterior part of the brain or exposure of the floor of the forth ventricle the animal will to "cease to blink," and the "whole appearance of the eye on the side on which lies the ventricle of the brain which you are pressing becomes like the eyes of blind men." Galen relates these findings to the close proximity of the optic nerves and chiasm to the area being compressed. Galen's experiments in applying pressure and cutting certain portions of the brain show his ability to create inventive approaches to complex neurological issues, namely, stupor and ocular responses.

Galen writes a discourse on experiments with the vocal cords. Chapter 7 is called *Operations involving the Loss of Voice.* He begins with, "if you wish to make the animal half-vocal you must [hemi-transect] it, if you want it voiceless, you must sever the whole cord." Galen then describes a set of procedures to remove ribs from a living animal using sharp dissection and a "cutting block." These experiments prevent the animal from exhaling and, as such, from the expiration necessary to permit voice production. The section is quite different from Galen's famous treaty, *On the Voice,* which is a set of experiments to cut the recurrent laryngeal nerve and paralyze the vocal cords. The chapter from "On anatomical procedures" is a description of the mechanics of the thoracic

muscles to create pressure within the rib cage which allows air to be forced through the larynx. Galen's eloquent, although brutal, investigation illustrates the authors ingenuity in experimenting with living creatures and his powers of observation.

In his "On anatomical procedures," Galen describes the experiments and results in a truly objective and scientific manner. However, he resists drawing conclusions about the neurophysiology of the structures involved. Galen presents his findings and does not try and explain what they mean in relation to his greater anatomical theory. By contrast, Avicenna inserts his opinions of neurophysiolgy relates it to his theory of the temperaments. Avicenna analyzes the anatomy of the nervous system in the context of his understanding of how particular structures are interconnected and fits his conclusions into his previously elucidated ideas about heat, cold and moisture.

Both Avicenna and Galen describe the coverings of the brain. Galen calls these the "meninx" and Avicenna simply calls them "membranes." Both authors differentiate between two separate layers. Galen states that the outer covering is "thick and hard." Avicenna agrees that the outer membrane is "thick and contiguous with bone." The two writers acknowledge that the deeper layer is in immediate contact with the substance of the brain. However, Avicenna comes to the interesting conclusion that the membranes provide a barrier between the brain and skull because the cerebral tissue sometimes alters its shape and swells, "as when shouting." Once again, Avicenna correlates a clinical observation, however unusual, to his discussion of anatomy.

In their discussion of the anatomy of the cerebral ventricles, both authors have important similarities. Avicenna states that the brain

"manifests longitudinally three cavities," and the most anterior is divided into "two distinct ventricles." He notes the presence of a "corridor" between the anterior and posterior ventricles and the existence of the quadrigeminal plate and velum interpositum, calling these the "roof with four pillars." Galen describes the anatomy of the ventricular system in detail, noting the passages between the cavities. For instance he states that the "large duct" below the base of the third ventricle "receives waste products from the anterior ventricles." This is a point on which Avicenna concurs and states, "in order to eliminate the excess from the brain, there are two conduits, on in the anterior ventricle, near its connection with the middle ventricle, and the second conduit in the middle ventricle proper."

Avicenna makes statements regarding the functions of areas of the brain, which are not found in the text of Galen. For example, he states that the union of the two anterior ventricles is "the place where ideas are formed" and is connected to "the place where ideas are preserved, a location most suitable for cognition and imagination." Avicenna leaps from illustrating the anatomy of the ventricles to an important point regarding neuropsychiatry. This indicates a major difference between Avicenna and Galen. Although Galen performed experiments which he sometimes failed to fully appreciate the physiologic and anatomic implications, it was possible for Avicenna draw to conclusions that were not based upon any experimental data whatsoever. Where Galen was sometimes guilty of an incomplete explication of his observations, Avicenna was capable of overanalysis of unsubstantiated data.

COMPARISON OF THE CRANIAL NERVES

Galen's concepts of anatomy are scattered throughout his many texts and statements on neuroanatomy can be found in a multitude of his works. Galen's specific examination of the cranial nerves, as discussed above, is detailed in "On anatomical procedures" and compares closely to Avicenna's description both in content and length of description. These descriptions of neuroanatomy are an example of how Galen's anatomical observations were gathered and organized by Avicenna. In comparing the two author's statements many similarities can immediately be recognized. However, subtle differences begin to arise when some of the finer aspects of the authors' opinions on physiology and structure are examined.

Avicenna uses Galen's method of grouping the nerves and employs the same numbering system. Both authors state there are seven cranial nerves. Galen briefly discusses an apparent controversy regarding the numbering of the cranial nerve which existed during his lifetime. He states that the ancient anatomists Marinus and Herophilus disagreed on whether there were seven or more cranial nerves. Galen emphatically sides with Marinus who concluded that there are seven pairs. He explains that his belief is based on animal dissections and states that anyone who would argue with his conviction has not performed their own studies and is "like a seaman who navigates out of a book." Galen and his contemporaries were probably the first physicians who paid close attention to the numbering of the cranial nerves. Avicenna accepted this doctrine without hesitation and it was through his *Canon* that Europeans learned and passed down the dogma of seven cranial nerves. It was not until anatomical studies began to be performed on human cadavers in the eighteenth century that Galen's

doctrine was reversed. The modern classification of twelve cranial nerves was first presented by a German medical student, Samuel Soemmering (1755-1830), and was based on his anterior to posterior study of the foramina in the cranial base which act as the windows for the nerves' exit from the skull as they move towards their target organs.

Avicenna and Galen do not consider the olfactory bulb as a cranial nerve proper. Galen quickly passes it over, calling it an "outgrowth" of the larger nerves proximal to it and Avicenna's brief description of the olfactory bulbs is of two "prominences." The two anatomists proceed to discuss the optic nerve and vision in some detail.

Avicenna and Galen on Vision

Avicenna's discussion of the optic nerve and chiasm, what he and Galen refer to as the first cranial nerve, is especially interesting. Avicenna states that the optic nerves are "short and hollow," and he accurately likens their substance to that of brain itself (in contrast to other cranial nerves which are describes as "harder"). Avicenna proceeds to describe the optic chiasm which he compares to a crucifix. He notes that some fibers from one tract cross to the opposite eye while other fibers remain uncrossed. Avicenna reminds the reader that Galen was aware of the partial crossing of the optic fibers. He then lists three advantages of the partial crossing.

First, Avicenna states, is the issue of vital force. The ethereal vital force, according to Avicenna, is a vapor, literally "spirit" or *rooh*, [27] which is derived from the light portions of the humors, and is carried by the blood to all organs and enables them to perform their various

functions. Vital force is the primary requirement for life, defined by Aristotle as "motion of beings," but distinct from "soul" or "anima" which is personal and immortal. Sensory and motor neural impulses are considered a secondary type of energy and a manifestation of the "discharge" of vital force through the arteries and sympathetic and parasympathetic nervous systems.

The optic nerves, Avicenna states, are able to divert vital force from an injured eye to its healthy counterpart, by way of the hollow nerves joining at the chiasm. He supports this notion by saying that when one eye is lost, vision becomes sharper in the other eye. Avicenna further proposes that a bilaterally simultaneous pupillary response to darkness is caused by movement of vital force between both globes. The second advantage of a crossed system is that overlapping images are recorded as a single image in the chiasm. In the case of a "squint," vital force is blocked from one eye and double vision ensues. The final advantage of the chiasm listed by Avicenna is that the nerves are better able to "support" one another and, thus, allow the eyeballs to be close to the brain.

In the discussion of the optic nerve, Avicenna's and Galen's writings begin to diverge. Both writers state that the optic nerve is the first cranial nerve. However, Avicenna moves the discussion from an anatomical observation (the decussation of the optic nerves) to a discourse on the physiology of vision. Avicenna's statements on the principles of sight can be compared to a similar discussion found in Galen's major physiological work, *De usu partium corpus*, or "On the uses of body parts." [33] Translated into Arabic from Greek in the ninth century A.D., the sixteenth book of Galen's work is subtitled *On nerves, veins and arteries* and

contains prolix discourses on the anatomy and physiology of the nervous and vascular systems. Section V is a discussion of the optic system and corresponds to Avicenna's remarks about the physiology of vision.

In *De usu* Galen states that the optic nerve is "softer than all the nerves" because sight is the most superior sense and it has been mandated by nature that soft nerves should be "joined with parts needing minute perception." [32] Galen further states that the eyeballs receive a continuous flow of "luminous, light-emitting pneuma" originating from the brain, specifically from the cerebral ventricles. Galen defines pneuma in terms similar to Avicenna's interpretation of vital force and states it was the primary energy responsible for setting living beings in motion, referring to the Aristotelian definition of life. The optic nerves are a conduit for pneuma and originate in the "two anterior ventricles of the brain," the site of pneuma production. Avicenna, however, opposed Galen on the point of origin of the optic nerves. In fact, Avicenna states in the *Canon* that the "ventricles of the forebrain" give rise not to the optic nerves, but to the olfactory "nipple-like prominences." [27] Galen explains that the optic nerve's structure is hollow so as to accommodate the flow of pneuma, and soft to account for the necessary perception of visual details, for instance, "dispersed millet seeds." Here is a significant example of how Galen accepted certain doctrines of the ancient Pneumatic school that believed that breathing was a manifestation of the pneuma shared by all living things. This view was a key aspect in his understanding of the flow of pneuma from the ventricles to the eyeballs. Avicenna, on the other hand, is concerned with the *rooh*, or vital force, which flows between the eyes, crosses at the chiasm and is involved in supporting vision.

Cranial Nerves II to VII

Both authors state that the second cranial nerve, the oculomotor, innervates eye muscles. Galen's description focuses on the texture of the motor nerve, which he called smaller and harder than the hollow optic nerve because thin, tough nerves supply muscles and are not involved in sensory perception. Avicenna agrees that the oculomotor nerve is tougher, but speculated that it is because it is "unsupported" by other nerves.

With the third cranial nerve (trigeminal and sympathetics), Avicenna gives a detailed account its divisions into four branches, describing precisely its distribution and the structures it innervates. Galen recounts similar divisions of the cranial nerve, but dwells on the way in which the nerve penetrates dura mater and fails to discuss its distal attachments.

The description of the fifth cranial nerve, the facial and auditory, becomes a platform for Galen to launch into a polemic regarding the true numbering of the cranial nerves. He ends by describing the passage of the fifth nerve into two canals, the auditory and a "blind" one, presumably the internal acoustic meatus. Avicenna also describes the "blind" canal and goes on to explain the path which the facial nerve follows and some of the muscles it innervates. He states the temporal nerve must be hard but not thick "as that would have interfered with movement." [27]

Galen states that the sixth nerve is comprised of a bundle of three nerves and should be considered as one entity. In his version of the fifth nerve, Avicenna systematically lists the foramina of the glossopharyngeal, vagus and accessory, their course, innervation of various structures and the

path of the recurrent laryngeal. He provides an accurate account of the muscles of the larynx and their dependence upon the brain, which, he says, ultimately controls the human voice by way of the nerves. Galen spends considerable time discussing the recurrent laryngeal in *De usu* and arguing that because the nerve is involved in speaking, it needs a strong, thick structure to wrap around and gain stability, and, as such, attaches to the aorta before turning upward to the larynx. [32]

Although Avicenna recounts some of the basic features of the Galenic description of cranial nerve's qualities, namely thickness and hardness, Avicenna also indicates the physiologic requirements of each nerve. The optic nerve needs to be large so as to accommodate the flow of vital force. Other nerves, such as the lingual and temporal, are hard because of the lack of physical support they receive from nearby nerves or structures. Alternatively, Galen maintains that the texture of nerves depends upon the "superiority" of the sense or function it performs. Sight and hearing are the "finest, subtle, complex and purest" [32] of senses and require large, soft nerves to communicate with the brain. Galen's conclusions are based on his view of the teleological function of nerves and the hierarchical structure arbitrarily assign to them. In the descriptions of Avicenna, functional conclusions seem to be more logical. Avicenna says that a particular nerve's form depends on its proximity to the brain and support it receives from adjacent structures as well as its function. Avicenna's statements have a greater degree of logical coherence and physiologic foundation.

COMPARISON OF THE SKULL AND VERTEBRAE

Significant similarities exist between Avicenna's and Galen's description of the skull and vertebral column. In his *General Description of Bones and Joints,* Avicenna uses what is largely Galen's classification of the joints. Both authors explain the difference between a joint and hinge, which is a ginglymus and both discuss the diarthrosis, synarthrosis, and gomphosis. The definitions compare with Galen's introduction to *De ossibus.* One difference is that Avicenna provides more examples where Galen is more apt to give solely definitions.

In his discussion of the skull, Avicenna begins with an explanation of its function, which is protection. The fact that it is made of several bones gives it two advantages, that is, localizing injury and variability of thickness. Avicenna also notes craniosynostoses, which he credits Galen for describing. Galen's first chapter of *De ossibus* is called *Bones and Sutures of the Cranium,* where he writes of cranial sutures and the number of bones which make up the skull. He mentions the normal shape of the skull, and the possibility of its deformity but does not elaborate on the varieties of geometrical pathologies to the extent that Avicenna does.

Both authors give considerable consideration to the sutures of the skull. Avicenna and Galen give a detailed account of the coronal, transverse and lambdoid sutures. However, Galen counts two temporo-parietal sutures as well as sutures of the maxilla and sphenoid bone in his description. The two anatomists agree on the number of bones in the head. Galen states that there are six plus the sphenoid, and he lists two parietals, two temporals, the occipital and the frontal, thus, yielding seven cranial

bones. Avicenna states "there are five bones in addition to the two parietals," and lists the same bones as Galen.

Avicenna writes a section entitles *Functions of the Vertebral Column*, where he list four purposes: to allow passage of the spinal cord, protect the organs of the thorax, provide a foundation for the skeleton and maintain position while standing. Galen does not describe functions of the vertebrae, but proceeds to describe the types of bones in the spinal column. Both authors state that there are twenty-four vertebrae, seven in the cervical region, twelve in the thoracic, and five in the lumbar. The authors state there are three vertebrae in the sacrum and, finally, one coccyx.

Although chiefly known as an anatomist, Galen described several interesting experiments and operations in the course of his writing. In his "On anatomical procedures," chapter 6 of Book VIII, which is mainly concerned with the anatomy of the thorax, Galen writes of an *Operation on the spinal cord*. He states that one can perform such an operation on both large and small animals, which suggests that the anatomist had much experience in experiments on living creatures. Galen recommends "an instrument of my own devising, like the so-called sharp-pointed bistoury," for a dissection of a young pig. He states that using his sharp scalpel one can clean away the skin and then insert an elongated knife "as far as the joints of the vertebrae." Then Galen describes how he removes spinal muscles and exposes the transverse processes, "to get an accurate view of the vertebral joints."

Once the spinal cord itself is exposed, Galen briefly describes the lesions various types of transections can produce. He says, "sever the spinal marrow transversely and completely, unless you wish to half-paralyze it." Galen further illustrates the complexity of the cord by

describing other lesions. He states, "when the spinal marrow is cut in the middle, straight downward, it does not paralyze either of the intercostal muscles. . . .When cut transversely, if only the half is severed, all the nerves on that side are paralyzed in series."

Galen shows that specific types of transections lead to hemiparalysis, while others cause full paralysis. He was adept in performing delicate dissections on living animals and demonstrating that precise hemisections of the spinal cord, or "marrow," are responsible for controlling movement of the ipsilateral portion of the animal's musculature. Interestingly, he does not provide commentary on the procedure or discuss its significance, such as the possibilities of tracts. Galen also fails to make clinical correlations with his discoveries. There are not examples of human diseases or accidents with produce similar hemiparalytic effects upon the body.

In a subsequent chapter called *Transverse sections of spinal cord*, Galen goes into more detail regarding his experiments. He states, "if you sever [the cord] completely between the third and fourth vertebrae, the animal at once ceases to breathe." He recognizes the fatality of the procedure when performed at the first or second vertebra, which produces a lesion in the upper medulla. Galen further states that cutting the cord "beyond the sixth vertebra, all the muscles of the thorax become motionless immediately and the animal breathes in only by means of the diaphragm." He notes that the pectoral muscles are paralyzed when sectioned beyond the sixth vertebra and states that the level of lesion, which is the level where the lateral and medical pectoral nerves enter the cord, is different in man and apes. Galen describes how caudal progression cord sections produces varying effects. He states, "the further you advance towards the lower vertebrae the more muscles of the thorax you will leave active." He

concludes that the nerves entering the "phrenes," or diaphragm, are the ones which are vital for the preservation of breathing in the animal.

It is unclear if Avicenna was aware of Galen's experiments on the spinal cord because he does not include any relevant statements in his sections on the spinal cord and anatomy of the skull.

ORIGINALITY OF AVICENNA'S CONTRIBUTIONS

Avicenna's *Canon of Medicine* is fundamentally a medical compendium largely based upon ancient Greek sources, chiefly the philosophic teachings of Aristotle and anatomic studies of Galen. Yet the work has its own distinctive character due to Avicenna's unique talent of selection, organization and interpretation of classic material. Avicenna's writing has a great degree of logical coherence and physiologic foundation compared to his Greek predecessors.

The ideas Avicenna puts forth in the *Canon* have an Aristotelian framework with much of its bulk derived from Galen. He was an unparalleled organizer of classical medicine. In addition he provided interesting commentary on the material he was summarizing. Avicenna continually pointed out that the physiological and psychological views of Galen and his followers were different than those of Aristotle. For example, the Galenic view was that the heart and brain were two of several primary organs, but Aristotelian doctrine usually held the heart to be the primary organ of the body, and this opposing conclusion led the two Greeks to different ideas about blood flow, sensation, motion and the origin of speech. Avicenna agreed with Galen but also established his own hierarchy of importance based upon the temperament, consistency and texture of organs.

In a different example, Avicenna sided with Galen in regard to conception. Aristotle had claimed that the active force was contributed entirely by the male, whereas Galen stated that both males and females emitted sperm which combined equally to form the fetus. [31]

Avicenna was known to have drawn some of his work from the medical encyclopedia of Razes and *Liber totius*, the survey of medicine by Haly Abbas (d. 994 A.D.). He was also aware of another work which summarized Greco-Arabic medicine and divided it philosophically into theory and practice, the *Isagoge* of Joannitius, which was translated into Latin from Arabic in the eleventh century. The text is a brief collection of medical opinions and describes the naturals, the non-naturals and the diseases of things against nature. As compared to the other works of his contemporaries, Avicenna offers a fuller and more intellectually demanding account of medicine with a better organization. The other writers also summarized the teachings of Galen, but Avicenna was the only one to offer comparisons with Aristotle and place medicine into the context of natural philosophy, thus ensuring the place of medicine alongside of the intellectually prestigious fields of astronomy, astrology, physics and philosophy. [31]

As discussed above, much of Avicenna's neuranatomic discussions are based on the writings of Galen. However, the Persian thinker did more than merely regurgitate the concepts of his Roman predecessor. In his general discourse on nerves, he strongly asserts the fundamental central role of the brain in all neural function. Elsewhere in the *Canon* (Book 3, *On the Brain*), he openly disagrees with Galen's concept that brain substance is soft to allow changes in shape in response to imaginations. Avicenna retorts "this is the opinion of Galen, while I say that the brain is created soft, so that it can be fatty, thereby nourishing the respective nerves." [5]

In the discussion of the physiology of vision, Avicenna strays slightly from the descriptive, analytic language which makes up the volume of the

chapter, to a more thoughtful reflection on function. Most of the sections on anatomy were concerned with the *material cause* of medicine, [38] that is, the physical substance which was studied in dissections, the part of medicine which could be seen and felt. In his discussion of the optic nerve, Avicenna allows himself to become concerned with the *formal cause* of sight, in other words, he asks the question, "how is it that one is able to see?" In this section a difference between Galen and Avicenna becomes obvious. The former's "On anatomical procedures" is instructional in the art of dissection and, as such, provides a description of the cranial nerves in relation to the brain. He limits his statements to the most proximal aspects of the nerves and their relation to each other. The physiology regarding nervous structures is presented in *De usu,* where the anatomist's language is meandering and verbose. Galen bases many of his conclusions upon teleological assertions of the importance of nerves within a philosophic scheme, i.e. the superiority of the sense of vision. Avicenna's *Canon* has a logical, analytic organization, its descriptions of cranial nerves are more systematic and include details of the structures they innervate. The physiology of the cranial nerves seems to rely upon anatomical knowledge and not philosophic dogma

Avicenna's discourse on vision allows the modern reader to glimpse the author's synthetic and organizational abilities as well as his philosophic perspective. Avicenna drew on Galen as a source of anatomic facts, alternately referring to Galen's concepts directly or as "what is commonly known." [27] Yet his own interpretation of physiologic questions was unique. The Persian's understanding of "vital force" is quite different from the older concept of "pneuma" found in ancient Greek philosophy with which Galen was familiar. Without abandoning totally the Galenic

dogma of the "pneuma" reaching the brain and being modified by it, Avicenna assertively proposes the brain as the cardinal center of controlling neural processes and source of nourishment and sustenance for the nerves.

The use of "vital force" resonates with an appreciation of life which is granted from an omnipotent being. Avicenna continually paid homage to God. Many chapters begin with brief prayers and the *Canon* abounds with invocations of the "great wisdom" and "favor" of God which is evident in the logical and graceful organization of human anatomy. [31] These religious beliefs are woven into Avicenna's neurologic doctrine. In the *Canon*, a cohesive understanding of the neuroanatomy of the optic tract is unified with metaphysical concepts of the energy which animates life. Avicenna's theory of sight, in using an idea accepted by the ancients, namely vital force, is intellectually satisfying and simultaneously religiously sound.

In the two authors' discourses on neuroanatomy obvious similarities exist, yet significant differences can be witnessed. Avicenna's statements regarding the brain contain theoretical discussions. He presents a brief schematic view of central nervous system anatomy and goes into an analysis of the brain within the context of his physiologic theory of the temperaments. Avicenna explains that the "cold and soft" brain possesses certain advantages. Avicenna's writing flows from anatomy to physiology. In his "On anatomical procedures" Galen restricts himself to discussing technique. Another theme of Avicenna's is the consistency of the organs. He explains that the softness of one organ must be balanced by the hardness of its associated structures. Avicenna also makes interesting statements about how the softness of the brain relates to its sensory perception.

Function, consistency and texture are significantly interrelated according to Avicenna.

Galen does not present a unified theory of neuroanatomy and function. He does, however, make penetrating observations. For example, Galen performs a variety of experiment related to thermal protection, the relationship between damaging specific cerebral structures and consciousness or paralysis. However, he resists making statements about the physiology of his findings. Galen simply presents his scientific experiments and does not fit the data into a grand scheme of the humors.

Avicenna makes some remarks regarding neuropsychology. He states the brain alters its shape when one performs certain actives, such as shouting. He makes clinical observations which are correlated to his teaching about anatomy. Avicenna's statement regarding the locus of cognition and its storage have no counterpart in Galen. The assertion is an example of how Avicenna applied his concepts of medicine and physiologic assertions to the anatomical studies and experiments that he learned from Galen.

While containing many similarities, the two authors' opinions on physiology and structure of the cranial nerves have notable differences. Both employ the same numbering system and agree that there are seven cranial nerves. However, in the discussion of the optic nerve, they begin to diverge. Galen states that the eyes contain pneuma. He states optic nerves conduct pneuma which originates in the cerebral ventricles. Avicenna, however, states that the ventricles are continuous with the olfactory nerves. Avicenna also discusses the texture of each cranial nerve. Optic nerves accommodate the flow of vital force. Other nerves are hard and have little bony support. Galen states that texture is related to the importance of each

sense. Large, soft nerves support sight and hearing, the finest of senses. Galen's statements depend upon his philosophy of the superiority of certain senses.

There are differences between Avicenna's and Galen's discussion of the skull. Avicenna provides more examples and Galen is more content to give definitions. Both discuss the normal shape of the skull but only Avicenna elaborates on craniosynostoses. The two anatomists concur that seven is the correct number of bones in the head and both authors agree that there are twenty-four vertebrae. In his famous experiment on the spinal cord, Galen shows that specific types of injuries lead to hemiparalysis and full paralysis, but fails to give examples of diseases or accidents that produce similar effects in patients.

CONCLUSION

The *Canon* was the concise expression of most of the key concepts of tenth century medical teaching. It was a unique text in that it captivated physicians in the West for centuries and was a mainstay of medical education until nearly the year 1800. Avicenna's synthesis was based upon Galenic anatomy and medicine, which, along with Aristotelian natural philosophy retained a hold over the minds of most educated men trained in the Western world. Renaissance university medical curriculum was divided into two branches of medicine: *theoria* and *practica,* the division which was established by Avicenna. The *Canon* began to loose some of its popularity and strength in academia in the sixteen century as critics, in their commentary on ancient texts, suggested that the separation of medicine into distinct areas of theory and practice as one of the main weaknesses of university curriculum. [31] Renaissance humanism, the appreciation of classical texts in their *original* language, had became prevalent towards the end of fifteenth century. Their polemic against translators of Greek and Arabic works began appearing in medieval commentaries. Arabic medicine in general and Avicenna in particular began to receive increasing criticism. The intellectual climate had turned against the *Canon* so that by the seventeenth century, its dominance as a central medical textbook had begun to decline. [31]

Although intellectually satisfying and medically detailed, the *Canon* contains some weakness. Because it was largely derived from Galenic sources, Avicenna occasionally allowed the inclusion of inconsistencies, which were merely restatements of incongruities found in Galen's works. For instance, in Book I Avicenna states that the urinary bladder is made of

a single tunic, or covering. However in Book III, Avicenna's account includes the description of the bladder having two tunics. This discrepancy is similarly found in Galen. In *De usu partium* and in one passage of *De naturalibus facultatibus* Galen assigns the bladder one tunic. However, in a second passage of the later work, the author describes the bladder as having two tunics. [31] Another difficulty of the *Canon* lies in its structure, which is organized around ancient concepts such as humoral theory, and the layout of subjects may seems foreign to modern readers. The arrangement of topics is satisfactory for subjects such as the treatment of a particular disease but it is less helpful for studying certain aspects of physiology and anatomy. The principles of physiology and anatomy of bones, muscles, nerves, veins and arteries are discussed in Book I; but the accounts of the anatomy and some further discussion of the physiology of other major organs such as the brain, lungs heart, digestive and reproductive tracts are scattered through the opening of chapters of the twenty-one Fen of Book III. [31]

The neuroanatomical writings of Galen and Avicenna are an example of how the teaching of ancient medical science relied strongly on theoretical knowledge. Prior to the Renaissance, medicine was divided either into highly intellectual discussions or the day-to-day practice of laying hands on the sick. Doctors could expend their efforts on either academic dissertations in a royal *salon*, or visit the sickhouse, depending on their wealth and social position. From their works it seems that Galen labored at the pursuit of pure knowledge and Avicenna managed to maintain his academic appointments while being a prolific writer and rounding on his patients. A large part of the Galenic corpus is a study of the more intellectual aspects of medicine. His concern is the presentation

of an accurate description of the structure of the human body and some explanation of its mechanics and physiology. It is difficult to know precisely what the doctor-patient relationship was during ancient times and whether or not the practical aspects of being a doctor were influenced by a keen knowledge of anatomy. Galen was probably an important and socially significant physician based upon his relationships with various Roman emperors. Ancient medicine partlial relied upon the character and charisma of indiviudal physicians who had little else besides a few herbal remedies, hot or cold compresses and minor surgery to "cure" their patients. Although the neuroanatomy of Galen as handed down to Avicenna probably had little influence on the actual practice of medicine in the hospital or at the bedside, it does offer important insight on the modes of medical education, the intellectual life of ancient physicians and their focus on the sometimes theoretical discussions of anatomical facts.

In summary, Avicenna's concepts on neuroanatomy provides a specific and highly focused example of his overall paradigm. He integrated the prolific, fragmented ideas of Galen, which represented the knowledge base of the period. His synthesis of the structure and function of the nervous system were profoundly influential. Avicenna's work provided European and Eastern physicians and students an organized approach to medical knowledge in a single text than was otherwise available in the voluminous compilations of Galen's books. No relevant or significant medical fact known prior to the tenth century was left out of the *Canon*. This is perhaps why the *Canon* remained the standard medical textbook in the East and in Europe for the next six centuries. Focused scholarly analysis of individual topics in the *Canon* may continue to shed light on the true ingredients of their originality and impact in medicine. Avicenna's

extraordinary powers of synthesis and organization remain impressive and significant now, over a thousand years after the birth of the Prince of Physicians.

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